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ABSTRACT

Results from a study of problem solving in the domain of instructional design are presented. Subjects were eight teacher trainees who were recent graduates of or were enrolled in the Stanford Teacher Education Program at Stanford University (California). Subjects studied a computer-based tutorial--the VST2000--about a fictitious vehicle. The VST2000 has alternate sources of energy, which are displayed on a computer screen along with switches that can be manipulated using a mouse. By changing switch settings, users can change connections between different components and component states, resulting in simulated operation of the vehicle. One day after studying the VST2000, each subject designed instructional materials concerning: how to operate the vehicle; and general principles of energy storage, extraction, conversion, transportation, and use illustrated by the vehicle. A scheme for coding the protocols was developed, considering three aspects of the process of design problem solving: (1) subproblems; (2) types of knowledge used; and (3) problem-solving operation. Data from the eight protocols are presented, showing variations among designers in relative amounts of work on subproblems, their use of knowledge types and operators, and patterns over time in problem-solving activity. Variables used in this analysis are considered as general features of design problem solving and are discussed in relation to several published analyses in several domains. Forty-four figures; a 26-item list of references; and six appendices, including the text of the computer tutorial, are included. (SLD)

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Processes and Knowledge in Designing Instruction

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Stanford University
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This report presents results obtained in a study of problem solving in the domain of instructional design. Participants were eight teacher trainees who studied a computer-based tutorial about a fictitious vehicle, the VST2000. The next day, each participant designed instructional materials of two general kinds: about how to operate the vehicle, and about general principles of energy storage, extraction, conversion, transportation, and use that the vehicle illustrates. A scheme for coding the protocols was developed, considering three aspects of the process of design problem solving: subproblems, types of knowledge used, and problem-solving operators. Data from the eight protocols are presented, showing variations among designers in their relative amounts of work on subproblems and their use of knowledge types and operators, and patterns in these features over time in their problem-solving activity. The variables used in this analysis are considered as general features of

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design problem solving and are discussed in relation to several published analyses in a variety of domains.

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Introduction

We give an account of instructional design problem-solving within an information-processing-theory framework (Greeno & Simon, 1988; Newell & Simon, 1972). The design task represents a fundamentally different kind of task from those traditionally studied within this framework, in that it is not well-defined; it begins with fewer constraints, and allows the problem-solver greater discretion and creativity in how to go about arriving at a solution than the tasks studied in the classic problem-solving literature (e.g., chess, Tower of Hanoi, and cryptarithmetic). Therefore, this work extends the classic descriptions of problem solving to the domain of ill-structured problems.

Instructional design problem space

Information-processing theory conceptualizes problem-solving as a search within a problem space. The problem space is seen to contain discrete and well-defined knowledge states, including an initial state, the desired end state, and all possible solutions to a problem. Problem-solving is characterized as the movement from one knowledge state to another, by the application of operators, until the desired end state is reached. The analogous features of the instructional design problem space, as we define it, are the design state, which is the condition of the design at any given time, and design operators, which are used to construct the design.

The design state differs critically from the knowledge state of classic problem-solving theory in two ways. First, all possible design states cannot be defined beforehand. Design, being an inherently creative activity, does not allow us to know, a priori, what options a designer might propose. Second, the final design state is a matter of judgment; the designer decides when the task is completed.

Rather than attempting to predefine the precise design states that might occur in problem-solving, we describe the instructional design problem space in terms of the types of knowledge that a designer might employ. (We infer the particular knowledge a designer brings to bear from statements and actions made during problem-solving.) Three general types of knowledge are used to carry out the task: knowledge about the design task itself, knowledge about teaching, and knowledge about the content to be taught. We conceptualize the instructional design process as one in

Methods

Participants

Participants were eight students in the Stanford Teacher Education Program (STEP). Four of the participants had recently graduated from the program, and four were new students at the beginning of the one-year program. Within each group of four participants, one male and one female student were planning to teach high school science, and the other male and female students were planning to teach either high school mathematics or social studies. Participants were recruited through an announcement in one of their classes and were paid for their participation.

Subject-Matter

The experiments used a fictional device as the topic for instruction. The device, a fictional vehicle called the VST2000, was developed in previous research by Greeno and Berger (1987; 1990). The VST2000 has alternative sources of energy, which are displayed on a computer screen along with displays of switches that can be manipulated using a mouse. By changing switch settings, connections between different components and states of the components are changed, resulting in simulated operation of the vehicle with its different sources of energy. The display that the participants interact with is shown in Figure 1. (The components of the fictional device are analogous to components of a stereo system: the solar pack is like a radio receiver, the tablograph is like a turntable, and the vegetor is like a cassette player-recorder. This analogy was not mentioned to our participants, and none of them indicated that they recognized the analogy.)

The domain of this fictitious device is advantageous for three reasons: (1) it is of manageable size and complexity so that a detailed representation of knowledge about the device can be specified; (2) participants' knowledge about the device can be controlled to a great extent because it is not a subject matter that our participants have studied previously; and (3) a computer-based display and simulation were available for use in the research.

which the designer selects content to be included in the design according to parameters set by knowledge of task and pedagogy. In other words, the design state is constructed from building blocks of content knowledge, using task and pedagogical knowledge to influence the structure.

At least three operators are necessary to carry out this building process: one to select information and put it into the design, one to evaluate the design, and one to make changes in the design. We call these operators, respectively, propose, evaluate, and modify.

Instructional design schemes

There are several possible ways that one might set out to design a piece of instruction within the problem space described above. In this section, we will describe a few of these, as a preview to reporting, in a later section, how some instructional designers actually proceeded. One approach would be to brainstorm many possibilities, and select among them. (This procedure would require the addition of a select operator to choose among the proposals.) A second approach would be to lay out a general plan for the instruction, and then fill in the details. A third approach would be to organize the instruction around some general pedagogical principles. For example, the designer might think: "I want the students to understand the purpose of what they are learning," or "I want to give them as much hands-on experience as possible," or "I want them to discover the principles for themselves." A fourth approach would be to choose some information to begin with, and then add onto it piece by piece, evaluating the product and determining the next step as one goes along.

In the next sections, we apply the framework presented here to data from verbal protocols of participants designing pieces of instruction in order to develop a more specific description of the problem space and procedures of instructional design.

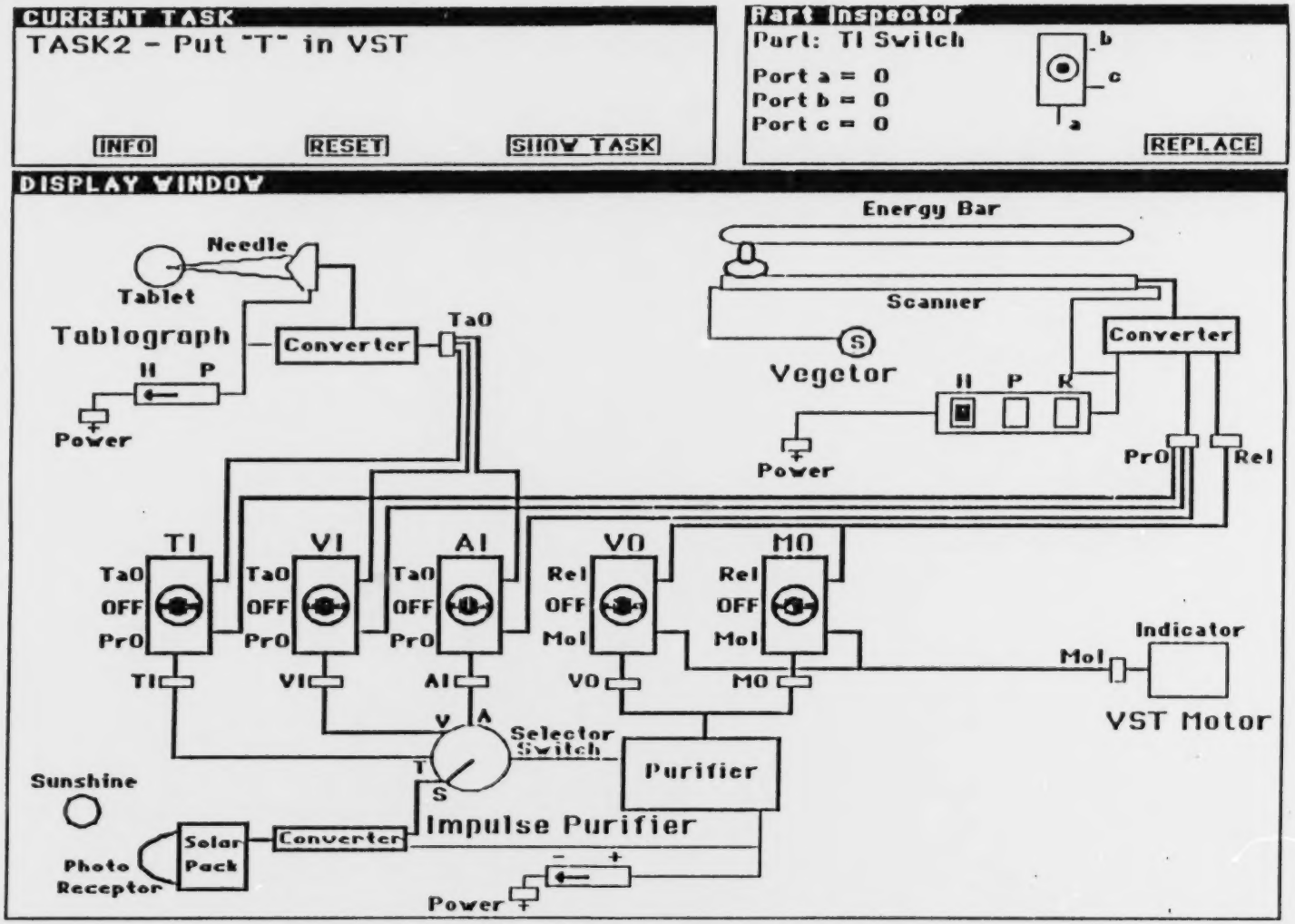


Figure 1. VST2000 System with Part Inspector

Procedure

Each participant took part in two one- to two-hours sessions on separate days. On the first day, participants learned about operating the VST2000 using a computer-based tutorial. On the second day, they were asked to think aloud as they designed two pieces of instruction about the vehicle.

Day 1: Subject-Matter Learning. On the first day, participants worked through the computer-based tutorial for the VST2000. In the tutorial, participants read text interspersed with 13 multiple-choice questions about the VST2000, its components, and the functional relations among the components. Some of the questions required the participant to manipulate the switches on the VST2000 to simulate the operation of the device. Participants were instructed to think aloud as they answered the questions, and their verbalizations were recorded on audio tape. An interviewer was present to turn on the tape recorder and remind participants to think aloud while answering the questions. If a participant made an error on one of the questions, the computer redisplayed the relevant instructional text until the participant answered the question correctly. The tutorial materials are presented in Appendix I. After completing the tutorial questions, the experimenter asked the participant questions about his or her major in the university and his or her background in science and technology.

Day 2: Designing Instruction. On the second day, the participants were given training in verbalizing their thoughts. Following a procedure adapted by Korpi (1988) from Ericsson and Simon (1984), participants were instructed to think aloud while solving a series of problems. These instructions are presented in Appendix II. When the participant said that he or she was comfortable with the thinking-aloud procedure, he or she was asked to design instruction for one of the two goals described below. After completing the first design, the participant was asked to design instruction for the second goal. The order in which the tasks were presented was balanced across the participants.

Goal 1 -- operations: For one piece of instruction, participants were asked to design materials that a teacher could use to instruct high-school-aged students in the operation of the VST2000. The participants were told to assume that the VST2000 was a real

machine and that they should design a general plan to use in teaching its operation.

Goal 2 -- principles: For the other piece of instruction, participants were asked to design materials that a teacher could use with high-school-aged students in a general science course. The VST2000 was to be used to illustrate general principles about science and machines. The participants were given a card describing the following general principles that they might address in their design: storing energy, extracting stored energy, converting energy, transporting energy, and purifying energy.

After finishing each piece of instruction, the participant was asked to review the design in relation to six aspects of instruction: main topics, sequencing, methods of presentation, materials, activities, and questions or problems for students to work on. These aspects were listed on a card that the participant saw during this review period.

While working on the design, the participant was permitted to refer to the VST2000 screen display, to write notes, and to ask the experimenter questions. After finishing both tasks, the participant was asked about his or her past experiences with teaching and instructional design and to comment on the tutorial.

Analysis of Protocols

The audio tape of each participant's design activity was transcribed and analyzed.

Segmentation. Each transcript was divided into segments that we call episodes. Each episode corresponded to work that was judged to address a single goal. The beginning of an episode was often signaled by a phrase such as, "The first thing I would do is . . .", or, "Then what I would do is . . . ." The number of episodes in the eight participants' first designs ranged from 25 to 61, with a mean of 38, and the number of episodes in their second designs ranged from nine to 43, with a mean of 18. Typically, there were about three episodes on each page of the transcribed protocols. To increase the comparability of episodes, if an episode was identified that was longer than one-half page it was divided at the most appropriate point. Some episodes had a hierarchical relation such that a superordinate episode was followed by a number of

subordinate episodes. We included these in a single episode and called the subordinate episodes "sub-episodes".

Coding Procedure. The categories used in coding protocol episodes are described in detail in the next section and listed in Table 1. The development of the coding scheme occurred interactively with coding of the transcripts; therefore, the categories that comprise the coding scheme were jointly determined by the transcripts themselves and *a priori* theoretical ideas about the nature of instructional design. Each protocol was coded independently by two coders, who then compared their codings and agreed on a final coding of each transcript. The length of printed text was measured and recorded in centimers (approximately six characters) for each of the coded categories from the final codings.

Coding Scheme

Each episode was coded for three features: subproblems, knowledge types, and operators. Subproblems are the component tasks on which a designer worked while constructing the design. Knowledge types are the types of information that the designer employs in planning instruction. Operators are the general processes by which problem-solving takes place. We adopt an expanded notion of operator, as compared with that used by Newell and Simon (1972). Whereas they described an operator as an information process that transforms an existing state of knowledge into a new state of knowledge, we use the term to refer also to non-state-transforming processes that are used during design.

Most of the subproblems and all of the knowledge types identified are specific to instructional design; they typically would not be used on a different type of design task. The rest of the subproblems and all of the operators are generic; they might be used on any design task.

During coding, each piece of text in the protocols was associated with at least one subproblem, one knowledge type, and one operator. However, it is possible for a designer to work on more than one subproblem or use more than one knowledge type at a time. Each of these three features is explained further below.

Table 1

Categories Used in Coding Protocols

Subproblems	Knowledge Types	Operators
Determine content	VST2000	Propose
Determine sequence	Science	Modify
Determine timing	Teach, general	Remove
Determine instructional transaction	Learn, general	Include information
Determine instructional resource	Available resources	Recap/reflect/evaluate/ monitor/justify
Determine constraints or requirements of the design task	Students	
Determine own constraints	Learn this	
Monitor progress or set out plan	Explicit teach this	
Clarify subject matter	Implicit teach this	
Content-relevant non-design issues	Instructional design task	
	Personal characteristics	

Subproblems

We identified in the protocols a total of ten types of subproblems. Five of these tasks are directly related to designing instruction. These were: (a) determine content, (b) determine sequence, (c) determine timing, (d) determine instructional transaction, and (e) determine instructional resource. Four of the remaining subproblems are prerequisite to designing instruction, but are not part of the design process itself. These are: (f) determine constraints or requirements of the design task, (g) introduce own constraints, (h) monitor progress on the design or set out a plan for the design process, and (i) clarify the subject matter to be taught. The final subproblem covers non-design activities, the content of which is related to the instruction, and which, therefore, might influence the form of the design. Each of these subproblems is described below, with accompanying examples.

Subproblems for Designing Instruction

Determine content. This task involves discussing the subject-matter of the instruction, including what topics should be covered, any directions the students should receive, and the goals of the instruction. A prototypical example of this task is:

> So the first direction I think I'd go through is to explain the power source of each one. Say, "Okay, the first thing you need to do is you have to have a power source to run the machine. You can use any one of the three power sources, be they the impulse purifier, the tablograph, or the vegetor. . . . [N1B, Episode 3]

Sometimes, designers discuss the content on a higher level of abstraction. An example of this case appears below:

> What I would probably want to do is have the next unit be some other sort of project or at least applied aspect where they have to problem solve--learn something about problem-solving. That way, this whole unit would lead directly into something else that would be, you know, pertinent to what you give the class. Since this is kind of extraneous to normal subject matter, it's more like skill development as an experience or exercise. [N4A, Episode12]

Determine sequence. This task involves discussing the order or temporal circumstance in which instructional events will occur. Because one must have some subject matter to perform sequencing upon, this task usually arises in conjunction with some other subproblem, such as Determine Content or Determine Instructional Transaction (see description below). It can occur as the dominant subproblem when a designer has laid out several topics and decides how to order them. An example of this case follows (the designer has just finished laying out the main topics of instruction):

> Now how do I want to order that? I would probably start off with the sun. Use that as my unifying principle . . . And then show how we can convert visible light into chemical energy using plants. Start there. . . . Go from there into solar energy with the photovoltaic cells. Use that. And there, I'd probably go into the stored heat . . . . [G1A, Episode 4]

More often, Determine Sequence occurs as a minor subproblem embedded within another subproblem. An example follows. (The dominant subproblem is Determine Content. Words printed in boldface were coded as Determine Sequence.)

> **So, we'd be starting off** with a power source to each one of the units . . . and the fact that it needs to be on for it to work. **Then** to the purifier and the fact that it always needs to be on. **Then** I'd go to the switches . . . **And then finally**, recharging . . . . [N1B, Episode 2]

Determine timing. In this task, the designer discusses the duration, versus the order, of instructional events. For instance, one might decide how many days to spend on a particular topic, as in the following examples: "So I would take, I think, two days on potential [energy]" [G3A, Episode12]; and "The tutorials will go two days, since it will take that long. You have Thursday and Friday" [N4A, Episode11]. Alternatively, timing might be determined on a more global level:

> I'm thinking about how long I'm going to make this unit, And I was thinking about possibly five days, just one week only. Maybe have that project go over the weekend. So, I'm going to make a basic calendar: Monday, Tuesday,

> Wednesday, Thursday, Friday, and a special block for the weekend, then Monday again. [N4A, Episode 8]

Determine instructional transaction. Instructional transactions are the ways in which students interact with the materials. They include methods by which the instructional materials are presented and activities in which the students engage. They also include questions, problems, and assignments the students are given. An example determining method of presentation is:

> I might talk about it, but I definitely want to be doing something visual. So if the machine is going to print out a sentence for me, it ought to say, well, "sure, this one goes up," and then put that on the diagram. So, if I were to be teaching this, I would diagram it on the board. [G2B, Episode10]

Some other examples of instructional transaction are: "When using the tutorial, I'd have them work at least in pairs" [N4A, Episode 4]; "I'd constantly be asking them if they had any questions" [N1B, Episode18]; and "Another idea, aside from the tutorial, would be to have them make a model of this machine, and market it" [N4A, Episode 6].

Determine instructional resource. This task involves discussing what materials or facilities might be used during instruction. An example would be: "[I]f I've got as many [computers] as I want, I'd have probably one for every two students . . ." [G1A, Episode 8]. Determine Instructional Resource often occurred in conjunction with another subproblem, such as Determine Instructional Transaction, as in the following example (words encoded as Determine Resource are printed in boldface):

> How am I going to present it? Roman numeral one--this introduction, is it going to be a lecture? Am I going to put **some different machines** out and have them describe the parts? That would be an option. To get **a bunch of very basic machines** and describe the parts. And then put this up on either **an overhead** or put it actually on **a computer screen** and describe the parts of this one. [G3A, Episode 54]

Prerequisites to Design

Determine constraints or requirements of the design task. Designers engaging in this subproblem seek to clarify the task that the experimenter gave them. This might involve trying to understand what they are supposed to do or what restrictions they are operating under. Two examples follow: "What am I supposed to teach them? . . . So we want a curriculum that's going to be using this as an example to keep coming back to for these different concepts?" [G1A, Episode1]; and "how thorough an understanding do they [need to] have? I mean, are they going to be required to be able to fix the machine? Are they going to need to know the different chemical reactions that are taking place?" [N1B, Episode1]

Determine own constraints . In this subproblem, the designer sets constraints that influence the form of the design. A constraint may take the form of a value or decision the designer inserts into the problem space that effects the overall design strategy. Constraints may be indicated in statements about the general philosophical orientation, general approach, purposes of the instruction, or rationale for the overall design, or they may be seen in assumptions about the design environment.

Two statements of general approach are: "I'm thinking that I need to not intimidate them by giving them so much information initially" [G4B, Episode 1]; and "I want them to come up with something on their own, but I need to give them some direction, so that they're not totally aimless" [G4B, Episode 90]. An example concerning the purpose of instruction is: "I guess I need to think about what the bottom point of this [is] . . . I have to decide what my focus is on that" [N3B, Episode12]. An example of a rationale is: "And that way, they would again be motivated, they would find practical use for that, and that might stick in their minds a little bit more if they have a concrete example" [G4B, Episode 19]. An example of making an assumption is: "My assumption is that the last unit was already on physics . . . so they have prior knowledge of simple circuits" [N4A, Episode 5].

Monitor progress or set out plan. This task serves the monitoring function of determining where one is within the design space, and the organizing function of setting out a map for the design. A good example of monitoring follows:

> Okay, now I'm looking back at your principles card. And we sort of touched on storing energy a little bit, because that would come under the lesson on potential. Not <u>how</u> it's stored, but <u>what</u> stored energy is and what can be done with it . . . Kinetic sort of touched on extracting stored energy. Converting would introduce--but we haven't gone into transporting; we haven't gone into purifying. Okay, most of it's been introduced now. We're into the second week; we're almost done with the second week. [G3A, Episode 22]

An example of planning is: "Okay, what I would like to do is brainstorm on paper. I see that there is a pad and pencil there. What I'm going to do is to make a list of what my various different options are . . . then decide how long I want this unit to be, and how many days it would cover." [N4A, Episode 2]

Clarify subject matter. Occasionally, designers become aware that they lack some information about the subject matter to be taught. When they acknowledge this, or when they attempt to figure out or remember some facts about the topic of instruction, we refer to the subproblem as Clarifying Subject Matter.

Some examples are: "I guess I don't really understand the theory behind purifying energy, 'cause I guess I never realized energy had to be purified, but I suppose it does . . . I suppose it's like crude oil," [N2A, Episode19]; and "I recall something about there is an energy difference with the impulse purifier or the sunshine . . . and here I need some help. I mean, what is the logic behind this? Why do I need to have one switch up and the other one down?" [G2B, Episode 39]

<u>Non-design Subproblem</u>

Content-relevant non-design subproblem. Some designers occasionally engaged in activity that did not contribute directly to constructing the design, but which could have influenced the design because the content was related to the instruction. This type of activity might include reflecting on one's own experience with the computer tutorial, as in the following example: "And you know, in reading yesterday, I'm not sure if I just missed it or what, but by the time the tasks came, . . . I was able to do . . . two-and-a-half of the four. I didn't know how to get the energy bar recharged." [G2B, Episode 23]

Knowledge types

Knowledge types describe the sorts of information that the designer brings to bear in working on the instructional design. We identified ten knowledge types that our designers used in developing their instruction. The knowledge types fit into five general categories: content, pedagogy, pedagogical content, task and personal knowledge.

Content Knowledge

We specified two general types of subject matter knowledge: (a) VST2000, and (b) science and other relevant knowledge.

VST2000. This consists of information about the VST device itself. VST knowledge is printed in boldface in the following example:

> So we'd be starting off with **a power source to each one of the units . . . to the tablograph, the impulse purifier and the vegetor. And the fact that it needs to be on for it to work.** Then to **the purifier and the fact that it always needs to be on.** Then . . . to **the switches, and how to switch them . . ., what the different labels mean** ... [N1B, episode 2]

Science and other relevant knowledge. Most of the data encoded under this category was scientific knowledge, but it also included any other content-relevant information. An example of science knowledge is:

> All of our energy comes actually from the sun in the form of light. And in ultraviolet, infrared . . . we can convert visible light into chemical energy using plants [G1A, episode 4]

An example of other relevant knowledge is:

> If you're three years old and you're trying to learn how to turn on the lights, you don't follow how the lights work. You just go to the switch -- flip the switch. And if you're operating a system, likewise. People on the space shuttle aren't going up there knowing where all the lines are; they're knowing where the switches are. And if there's problems in the lines, they're talking to Houston. [G2B, episode 29]

Pedagogy

We identified four pedagogical knowledge types: teaching in general, learning in general, available resources, and student characteristics.

Teaching in general. This category includes general knowledge about teaching, as well as general philosophical statements about teaching. Two examples indicating general knowledge are: "I'm assuming these will be fifty-minute classes" [N4A, episode 9]; and "oftentimes, sequencing can be affected by what textbook we're using" [G2B, episode 56]. A statement indicating a general philosophy of teaching might be something like "I try to employ not only speaking, but visual . . . I'm trying to appeal to their sense of touch, their sense of movement, sight, sound. And also . . . try and work on their reasoning skills" [N1B, episode 25].

Learning in general. This category refers to global statements about learning, for example: "Most people could learn how to operate something by just being given a textbook . . . or a recipe" [N4A, episode 32].

Student characteristics. This type of knowledge refers to statements about the students who will be receiving instruction, for example: "That might be a little over their heads" [G3A, episode 14], and "I'm not sure what . . . specific information they've received in class in terms of machinery or experience" [N4A, episode 3].

Pedagogical Content

Some statements made by the designers reflect an integration of content and pedagogical knowledge. We distinguish between

knowledge about learning and teaching this particular material, and also between explicit and implicit knowledge of teaching this material. "This material" refers to the subject matter of instruction, i.e., the VST2000, scientific principles, or anything else the designer includes as content.

Learn this. This category includes references to the designer's own experience learning about the VST2000, to the VST tutorial itself, to peculiarities of learning about this particular material, and to concern for the students' experiences in learning from this instruction. Two examples are: "In terms of operating this, the only things I was asked to do was to do a V, S, or a T, or . . . to recharge . . . the energy bar. So I don't think that would cause many people much difficulty" [G2B, episode 9]; and "There is a transfer of energy that they don't really need to worry about" [N1B, episode 6].

Explicit teach this. This type of knowledge consists of explicit references to the particularities or philosophy of teaching this material. It contains higher-order, abstract discussion of concerns about teaching this subject matter, and talk about teaching this material, rather than simple inclusion of propositions. If any general principles of pedagogy are included, they are discuss in relation to the subject matter at hand. An example using Explicit Teach This knowledge is:

> I would definitely try and bring the kids into it and not do lecture unless it was the only way to do it. It would be more conversations, dialogues, . . . as many different 'hands on' activities [as] possible. [G3A, episode 55]

Implicit teach this. This category includes discussion about teaching this particular material in which the pedagogical content knowledge is implied rather than being explicitly stated. It generally appears in simple statements about what the design will look like, without a rationale. It also includes knowledge of one's own design. This is the main type of knowledge used. Two examples are: "Then, . . . have them go through [the tutorial] like I went through it, and just have them play with it for a minute and try and get . . . the power on . . . in each power source" [N1B, episode 5]; and "Now it looks perfect. One day for each of these [topics], because that's one week" [G3A, episode 8]. Specific content knowledge often is embedded within Implicit Teach This knowledge, as in the following

example (the entire passage is considered to use Implicit Teach This knowledge; VST knowledge is printed in boldface):

> After I've said it's an earth vehicle . . . I'd just go into . . . all the information they give you, such as . . . **you can store energy here, you can receive energy, and--** that would probably be my first step . . . to talk about the system, and then define or talk about **the three different parts of it: the Tablograph, the Vegetor, and the Impulse Purifier**. [G2B, episode 4]

Task Knowledge

This category includes references to the instructional design task that was presented to the designer by the interviewer. A prototypical example would be: "So, I need to design instruction for high school-aged students to operate the machine" [N1B, episode 1].

Personal Knowledge

This category includes information about oneself as a teacher or instructional designer, and about personal experiences. The following example displays knowledge about self: "If I were to plan something, I'd always have to have three or four sources, so I have different ways to look at it. And that's the way I plan" [G2B, episode 3]. The next example describes personal experience: "I'm thinking back to where I grew up in Massachusetts. In the Boston area there is a museum of science, and I remember an exhibit on energy . . . " [G3A, episode 13]

Operators

Unlike subproblems and knowledge types, operators are mutually exclusive; only one can be applied at a time. We identified a total of five operators. Three of these serve to transform the design state, and the other two aid in shaping the design space and navigating through it. The three state-transforming operators are (a) propose, (b) modify, and (c) remove. The non-transforming operators are (d) include information, and a metacognitive one that we called (e) recap/reflect/evaluate/monitor/justify. These are described below.

State-transforming Operators

Propose. This operator is used for initial specification of the design, and is the primary mechanism by which the design is formed. It includes concrete proposals and elaborations, as well as speculation as to what the design might include. Speculation was included as part of this operator because it is a technique that many designers used to form their design without making overt decisions. They would consider ideas that might be included in the design, then continue as if those ideas were part of the design. A clear example of proposing is: "I'm thinking the best place to start would be to follow the format of the review box and start out familiarizing the students . . . with the parts of the machine" [G3A, Episode 6]. The following is an example of proposing by speculation "I'd be curious, just for myself, to see if some students went through and learned this one day, let's say in pairs, whether or not, without the tutorial, could explain it, just with a picture, to someone else, and see if they could just go in and operate it" [N4A, Episode 7].

Modify. This is one mechanism, along with the remove operator described below, by which designers alter their products. It might involve the replacement, reformulation, or repositioning of an existing design component. The following example applies the modify operator: "now I'm thinking about . . . not splitting the [class] into two to do it in groups. So I'm just going to do it in two's. . . the whole class will go straight to the tutorials" [N4A, Episode11].

Remove. This is the other way of altering an existing design. It differs from the modify operator in that it involves deleting part of the design, without replacing it with anything else. We included it in the coding scheme as a logical option but, in fact, only one of our instructional designers ever used it. In the following example, the designer has just proposed including a lab, then says, "but now that I think of it, just the demonstration would probably be as much as they could handle" [G3A, Episode 28].

Non-state-transforming Operators

Include information. This operator serves to bring new information into the design space, where it can be used. This may be accomplished through seeking information from the interviewer or the tutorial, or by activating information from the designer's own memory. The following is an example of seeking information: "I have

one question. You said something about details? . . . I didn't quite understand that" [G2B, Episode1]. Next is an example of activating information: "there are certain things you want to teach the kids. Certain general principles about science that are supposedly on your school committee's list of things they should know when they finish the course" [N2A, Episode 6].

Recap/reflect/evaluate/monitor/justify. This is a compound operator that serves a range of related metacognitive functions. It involves recapitulating or reflecting on the design in order to evaluate it or to monitor one's progress. It also involves reflecting on or explaining one's design process or justifying a decision. Reflecting on and evaluating one's design might look like the following example: "That's a basic overview of this unit. . . That's kind of intense, but [there's] no sense in trying to apply it to too many other things . . ." [N4A, Episode17]. A summary statement for monitoring progress might look something like: "So these, to me, that's what I think I need to go through" [N1B, Episode 2]. An example of explaining one's design process is: "I'm looking to see if there's any particular topic that would make the most sense to go [to] next" [G3A, Episode11]. An example of justifying a decision follows (in boldface): "if I were to teach something about this, first of all, I might say it's an earth vehicle, . . . **so that . . . right off the bat you know what you're dealing with**" [G2B, Episode2].

Results

For identification in this report, the eight designers are designated as follows: G1A, G2B, G3A, G4B, N1B, N2A, N3B, and N4A. The first letter indicates the group from which the designer came. The letter "G" indicates students who had graduated from the STEP program; the letter "N" indicates students who were new to the program. The final letter indicates the condition under which the designer participated. An "A" indicates participants whose first design focussed on principles; a "B" indicates participants whose first design focussed on operation of the device.

Summaries of Designs

We begin with an overview of the designs that the participants produced. More detailed summaries of all the participants' designs are given in Appendix III.

Operations Instruction. Half of the participants designed instruction for operating the vehicle first. G2B's unit will begin with an introduction about energy flow in the system and the three energy sources. Then the settings of switches will be discussed. The greatest amount of time will be spent in learning operational procedures, so students are "able to use different types of power and recharge the energy bar." The students "need to know how to do all the little things." G2B will emphasize diagrams in explaining about switch settings and have students trace lines of energy flow for different settings. G2B felt that a clearer overview of the material than that provided by the tutorial is needed. G2B described a variety of instructional techniques to be used, including peer-group tutoring, mnemonic devices for abbreviations in the diagram, and tailoring presentation of technical materials for students with different backgrounds.

G4B intended to design instruction that proceeds from a basic to a more advanced level in a step-by-step fashion. This instruction will begin with a definition of a motor and its parts, and with a description of the difference between local and non-local sources of energy. Discussion of energy conversion and purification will be followed with description and diagram of the three main sources of energy used by the VST2000. The instruction will then focus on the Impulse Purifier (Solar Pack), and a detailed description of its workings. Examples of solar energy's usefulness in everyday life

will be part of this section. At the end of this section, the students will be given time to ask questions and an exercise in tracing the energy pathway. Next, the instructor will present the Tablograph, noting which of its functions have analogues in the Solar Pack, and which are peculiar to the Tablograph. Again, the students will be required to trace the energy pathway from the Tablograph in the VST2000 at the end of this section. After this, the class will address the Vegetor, beginning with a comparison of it to the two other VST2000 energy sources. The students will be asked to come up with ways in which they think the Vegetor might be recharged. After this, the various functions and switch settings of the Vegetor will be gone over in great detail. The instructor will use a diagram to outline the path that the energy follows within this system. At the end of this section the students will be given a quiz on all three energy sources. After describing the need for an energy purification system, the instructor will ask students to devise the most efficient way to provide purification for all three energy sources in the VST2000. This will lead to discussion of the purpose and functions of the switches. The instructor will use the model of a heart to illustrate the principle of the selectivity of switches. The instructor will elaborate some basic rules for setting the switches in the VST2000, and then give the students problems to solve; for example, to direct energy from the Tablograph to the purifier. The instruction will continue to focus on the principles and practices of switching, with special attention given to the selectivity idea, and to the way in which the Vegetor can be recharged while the motor is running on an alternate energy source if the switches are set properly. Lower level students will be given the analogy of the human body to aid in their conceptualization of energy principles. The class as a whole will be assigned group projects in making illustrative posters, which will be shared with the class and critiqued after they are finished. The students will receive handouts with diagrams and written materials to help them understand the VST2000 operations. Also, the students might be required to solve problems in operating the VST2000 under a variety of conditions. The instructor might test the students on the material presented in the diagrams used to illustrate the VST2000 operations.

N1B's intention was to focus on "just the workings" of the VST2000, without worrying about "actual transactions and the conversion of energy." Instruction will begin by explaining the three power sources and the need to have a source's power switch on for it

to function. Then there will be discussion of the paths of energy flow from the different power sources through the switches. The function of the purifier will be discussed, along with the need to have its power on, circuit patterns for power flow will be emphasized, and the selector switch and the motor-input switches will be explained. The vegetor will be discussed in a separate section, with review of the alternative power sources. N1B will design a set of exercises for students to learn the operational variations for the vehicle. Finally, N1B will have the students practice running the VST2000 ("the machine itself") with the different energy sources and examine the actual parts of the machine, visualizing the flow of energy through the various switches.

N3B belongs to the group of participants who designed the operations instruction before designing the principles instruction. N3B's operations design focuses on elaborating the content to be presented in the instruction, but also specifies a great deal regarding the transaction, as well as the sequencing and constraints. Overall, the operations instruction designed by N3B is dedicated to providing the students with hands-on, experiential learning. Very little about how to actually operate the machine will be disclosed in a direct fashion by the instructor. Even so, the first part of N3B's instruction will include a comprehensive overview of the machine. Thus, N3B will begin the instruction with an general discussion of the VST2000, its advantages, its main power sources, and the comparative merits of these power sources, the last of these presented in tabular form. From here, the students will receive a demonstration of the actual operations of the machine, and will also be shown a flow chart that traces the path of the power as it flows though the VST2000. This will be accompanied by a detailed explanation of each of the energy systems in the machine. But after this, the instruction will involve little in the way of lecture or even guidance by the instructor. The next step, then, in the instruction will be to give the students ample time to play with the tutorial and figure out independently how to get energy from its source to the state where it will power the machine. This will happen for each of the three energy systems, starting with the Tablograph. The instructor will give the students more guidance with the Vegetor, because of its relative complexity, but the students will still be left to figure out as much as possible on their own. The instructor will increase or decrease guidance depending on the results of previous efforts. The students in this lesson will also be required to

determine all the possible combinations for the switches by themselves. Slower students will be helped by their peers and the instructor to some extent. At the end of the instruction, the instructor will recapitulate the important points about the VST2000, including the relative advantages of the differing energy systems.

G1A's operations instruction, designed following principles instruction (described below), will begin with discussion of the sun as a source of energy. G1A will use an analogy of the VST2000 with cars, with the rechargeable energy bar analogous to a refillable gas tank. G1A will illustrate absorption of solar energy with black and white plastic sheets, placed on the ground while students have a "tour" of the different parts of the vehicle. The energy bar and the power tablet will be discussed, noting the power tablet's advantage of not having to be recharged. The vehicle will be demonstrated indoors, lacking sunshine as a power source. Switches will be explained in the context of discussion of general properties of circuits. Students will have the task of devising their own schemes for making connections needed to operate the device in different modes. They will be given practice in the physical operation of the vehicle. In take-home assignments, students will write reports of what they are learning in the course, and a final exam will be to write a plan to keep the vehicle operating continuously for a 36-hour period in a variety of circumstances.

G3A will use the computer tutorial to teach students how to operate the VST2000. G3A will introduce the tutorial in a lecture format with a large screen for demonstrations, and then let students work through the tutorial individually. While students are working on the tutorial, the actual VST2000 will be available for them to observe and manipulate. The instructor will lecture, provide diagrams, and ask student for descriptions of the machines operations. The students will play motivating video games on the tutorial, and be able to see individual parts in detail. They will solve problems in setting the switches, and team up against each other in student-created problem-solving challenges. After completing the tutorial, students will get to operate the actual machine.

N2A will introduce the vehicle by stating that it uses the three different forms of energy, and will focus on procedures for setting the switches to use each energy source. There will be "no general

discussion of energy, or anything like that." N2A considered alternative ways to present the procedures: either by explicit instructions, accompanied with diagrams, or in a context that would require students to discover procedures that work. N2A's instruction will combine use of a computer tutorial and a real VST2000 vehicle for practice. Students will be evaluated by observing their ability to operate the vehicle without written or verbal instructions, with problems and questions about specific steps for operation of the vehicle.

N4A's operations instruction will use the tutorial. After an introduction to basic information about the VST2000, students will go through the tutorial enough times to learn it. N4A will expand the tutorial to include more tasks, especially tasks of making the VST2000 run "where something goes wrong." Following instruction on the tutorial, N4A will practice on the real vehicle. N4A did not design instruction using the real vehicle in detail, saying this would depend on the kind and amount of feedback available on the real control panel.

Principles Instruction. G1A's principles instruction, designed first, includes several topics in the domain of energy, including the sun as the initial source of energy on earth, conversion of solar to chemical energy in photosynthesis, stored electrical energy in photovoltaic cells, stored heat in water, and generation of electricity with wind. Electrical and nuclear energy will be discussed, with conversions between nuclear and electrical energy, and between electrical and mechanical energy, and the distinction between potential and kinetic energy. Energy topics also will include generation of electricity from burning coal or oil, and hydroelectric energy. Efficiency of energy use will be included. Discussion of the vegetor of the VST2000 will be related to biological topics. The tablograph will be used to illustrate a nonrenewable energy source, and the vegetor will illustrate renewable energy sources, along with photosynthesis, batteries, and chemical reactions. The VST2000 also illustrates conversion of energy from different sources to a single form, and conversion of that to mechanical energy by a motor. The VST2000 tutorial will be used, in a modified form, in a discovery-learning mode, and students will be given tasks of building circuits themselves, checking their designs against the circuits shown in the tutorial. G1A will also use a demonstration that energy is available in sunlight and an acid battery as additional illustrations of the principles in the unit.

G3A will begin instruction with an overview of the VST2000, including the parts of the machine and the types of energy sources. The instruction will proceed to a more detailed look at the three main energy sources, with one class period spent on each. After this, potential and kinetic energy will be discussed, with the aid of balls and roller coaster tracks for demonstrating the conversion of energy from one form to another. Storage and extraction of energy will be discussed as part of the section on potential and kinetic energy. Students will then be asked to relate their understanding of these types of energy to the various parts of the VST2000. After studying the concepts of raw and purified energy, the class will write an assignment on the reasons that energy must be converted. The instruction will connect what is being learned in class to energy forms with which the students are familiar, such as running water. A discussion on changing energy from kinetic to potential will lead into the topic of energy storage. The next topic will be solar energy: its collection, storage, and potential. Then nuclear energy will be discussed, with a cursory review of the principles of fission and fusion, and a comparison of the feasibility, potential, and by-products of these two types of nuclear power. The next topics will be fossil fuels, with a description of their origins, and the major alternative energy sources, such as tidal and geothermal energy. The instruction will relate solar, nuclear, and fossil-fuel energy to the Solar Pack, Tablograph, and Vegetor, respectively. G3A will present the transportation and conversion of energy in terms of getting the energy "where you need to use it," and getting it "in the form you want it." G3A will explain and illustrate the circuitry in the VST2000 using a stereo system with detached components, diagrams, transparencies, and a computer simulation. Simple machines will be brought to class for instruction in the principles of mechanics. The course will be taught, as much as possible. in a discussion rather than a lecture mode, and will include many lab activities. The instruction will include homework problems, short written assignments, and a final research paper.

N2A's principles instruction will focus on general principles, and will begin with a brainstorming activity to find out what students already know about energy. The first topics will be extraction and conversion of energy into usable forms, with the VST2000 used to show the idea that just one source of energy is needed for the vehicle at any given time. Next, transportation of energy and energy loss during transportation will be discussed.

Energy purification will be discussed, providing the idea that energy needs to be transformed from a pure to a clean and useable form. Energy storage will be discussed last because it is not central to the operation of the vehicle; N2A will emphasize that technologies for storing energy, such as solar energy, are important concerns for the future. N2A will use actual devices and instruments in the instruction, including electrical circuits with light bulbs, ammeters and voltmeters to measure loss of energy, and batteries and solar cells for storage and extraction of energy. The sequence of instruction will begin with experiments so students will obtain information first hand.

N4A designed a five-lesson unit, focussed on problem solving using the tutorial, with the knowledge they gained to be applied by analogy in later topics on scientific principles. The five lessons will be: (1) an overview, including the energy sources; (2) introduction to the tutorial, with students beginning to work on simple problems; (3) more difficult problems; (4) beginning to work on projects involving construction of a model of the VST2000 for purposes of marketing; (5) completion of models. After students have presented their models to the class, the next unit will consider more advanced circuits and problem solving in the form of trouble-shooting.

G2B's principles design included activities involving energy flow in different circuits. Topics in energy include fossil fuels and pollution, energy conversion, potential and kinetic energy, and energy transportation. A variety of activities will be included, using magnets, circuit boards, and conversion of electrical energy to heat. There will be general discussion of energy systems in different parts of the world, and research projects about topics such as locations of major oil sources will be conducted, rather than boring lectures on where oil comes from.

The principles instruction designed by G4B will begin with a question prompting group discussion regarding the food the students had eaten recently and the energy-related consequences of this. This discussion would provide description of energy conversion, storage, and transportation. The discussion would then move to energy extraction, centering on the question of how it is that the human body can extract energy from food eaten previously. After the class defines extraction, the class will be asked if the body has a purification function. A discussion of the kidneys will be followed

by a collective definition of purification and description of the use of energy in purification. The class will together define the five key terms in the principles instruction. After this, the class will discuss other forms of energy--hydroelectric, nuclear, gasoline--and their uses in motors and other machines. A general diagram of the VST2000 will show the different energy sources used to power its motor. The instructor will explain these energy systems, discussing them in terms of the five energy-related principles. The students will be shown where, in the VST2000's energy systems, these various functions of extracting, storing, converting, transporting and purifying are performed. The instructor will then focus on the Solar Pack in illustrating these functions. The next topic will be presented more interactively. The instructor will show the students an energy source in the form of a tablet and they will determine that an extractor, converter, transport system, etc. are needed. Finally, the instructor will explain the various parts and functions of the Vegetor in relation to these principles. The students will be given a simplified version of the switches and their operations. Activities for the class will include problem solving in groups. The problems will focus on how and where to get energy in circumstances such as being stranded on another planet, or needing energy in primitive times. The five principles will be discussed and exemplified as part of this exercise. The small group activity will help the students with interpersonal skills. Ultimately, this kind of problem solving could be related to real-world problems such as deforestation and political concerns.

N1B's principles instruction was intended to emphasize each "primary stage of energy itself," rather than switches and their functions, which had been the focus of N1B's operations instruction. The will be a discussion of solar energy, related to nuclear and battery power. Efficiency of energy receptors will be discussed, with solar-powered cars used to illustrate conversion of solar to mechanical energy. Switches will be discussed as mechanisms to control the flow of energy. The purifier will illustrate the need to convert energy to a usable form. The process of recharging the vegetor will be presented as a "sidetrack." A "final experiment" will involve measuring energy going into and coming out of the system to determine its efficiency. Student activities will include drawing energy pathways and reading relevant material on batteries and solar and nuclear energy. They will write papers about energy transfer, and solve problems about the efficiency of the VST2000.

As in the operations instruction designed by N3B, a good portion of the N3B's principles instruction will be dedicated to the students' hands-on exploration of the VST2000. The lesson will begin with time for the students to "play" with the tutorial to the point where they all have learned how to operate the VST2000 (e.g., collecting and transporting the energy, successfully manipulating the switches, etc.). The principles instruction, conducted primarily in lecture or discussion form, will begin with an introduction to the idea of potential vs. kinetic energy. The discussion will then turn to the idea and examples of the extraction of energy from sources where it is not readily available. Once energy is gotten, the instructor will explain, it must be converted to a usable form. The instruction will include steam engines and dams in its examples of how this happens, and will require the students to come up with some of their own examples. Transportation of energy will be introduced by the instructor's having the students generate examples from "real life" of energy transportation (e.g., power lines). Energy purification will be discussed in terms of the students' experiences with having to use adapters to convert energy when travelling in foreign countries. This instruction will, in general, use the VST2000 as an example of each of the principles addressed. Often this will be done in conjunction with the student-generated examples of real-life instances of these principles in action. Sometimes the discussion of the principles will precede discussion of the examples; sometimes the instruction will proceed in the reverse order. Questions about the students' experiences and examples will be an important part of this instruction. The students might work in groups. Visual media will be used to illustrate the explanations given by the instructor. A major assignment might be having the students observe an energy-producing facility (such as the Altamont windmills) and describe it in terms of the path the energy follows from its source.

Subproblems

For each subproblem of the coding scheme, the lengths of protocol segments coded as that subproblem were measured in centimeters (1 cm = approx. 6 characters) and recorded for each episode. We chose length as a measure because it directly reflects the amount of time spent on each subproblem.

Overall Amounts of Work on Subproblems: Figure 2a presents the lengths of protocol segments coded for each of the subproblems, summed across all the designers. The subproblems that designers worked on most were Determine Content and Determine Instructional Transaction, with Content occupying them almost twice as much as Transaction. The next most lengthy subproblem was Determine Instructional Resource, which designers worked on about a third as much as Transaction. All other subproblems were worked on somewhat less than Resources.

Figure 2b presents the frequency of occurrence of each subproblem summed across all designers. These frequencies are consistent with the subproblem lengths shown in Figure 2a, except for the Determine Sequence subproblem, which was distributed throughout the transcripts in short segments. For this subproblem, the graph of frequencies provided a more sensitive measure than the graph of lengths, but this was the only case in which the two types of graphs differed. In general, graphs of the frequency of occurrence of subproblems, operators, and knowledge types were highly consistent with the graphs of the category lengths. Since these two types of graphs show a consistent picture, we present only the graphs of category lengths.

Figure 2c shows the lengths of subproblem segments, summed across all designers, separated into the main design period and the review. Recall that in the review, designers were given a list of six aspects of instruction: main topics, sequencing, methods of presentation, materials, activities, and questions or problems for students. This list would encourage attention to a variety of the subproblems that we coded, if a designer had attended to only one or two subproblems in the main period. Figure 2c indicates that the distribution across subproblems in the review differed from the main period primarily in there being less material concerning the content of instruction. Figure 2d presents the subproblem lengths expressed as a percentage of the total length for the main and

Figure 2a

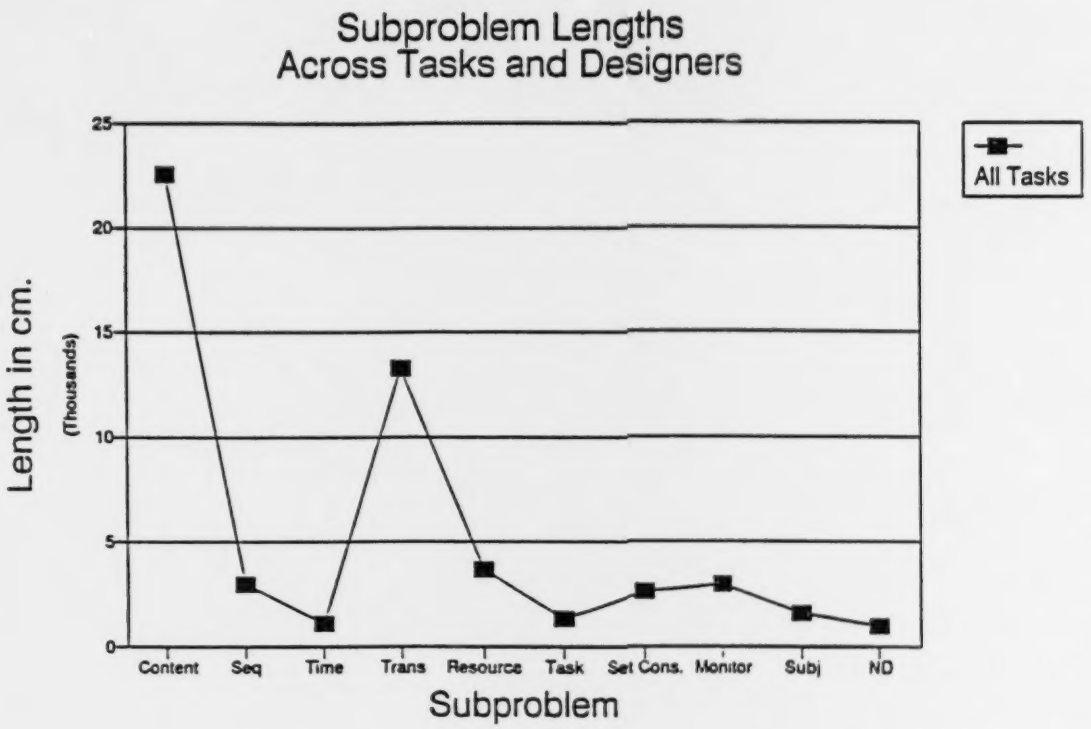


Figure 2b

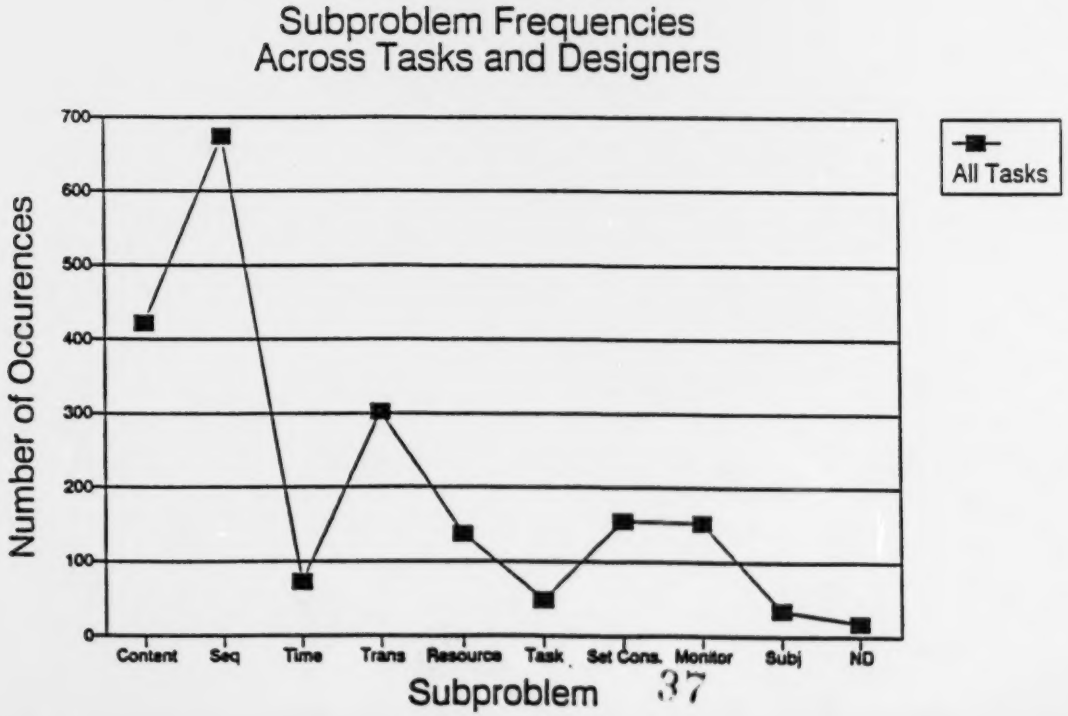


Figure 2c

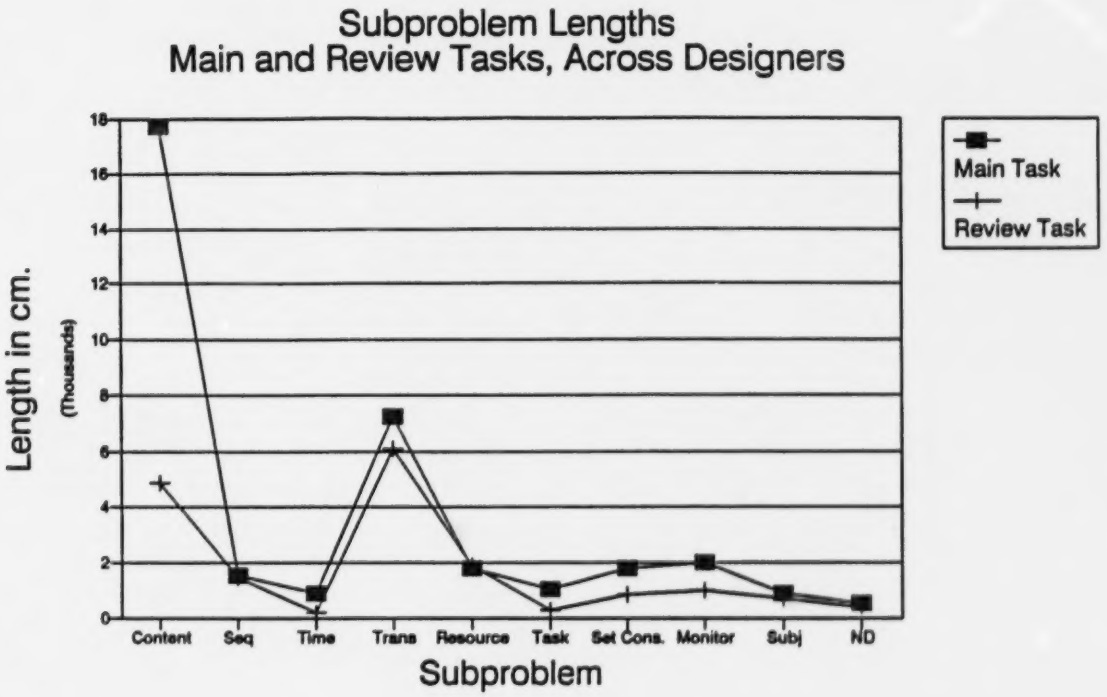
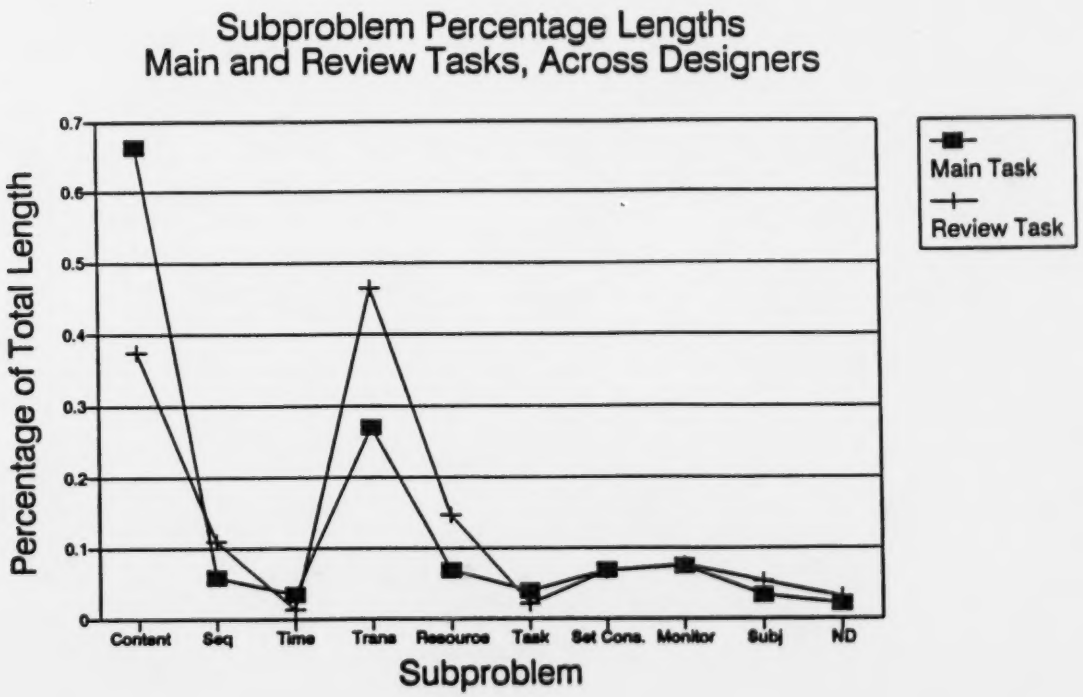


Figure 2d



review tasks. A greater percentage of Determine Transaction was observed in the review task, reflecting the instructions for the review that encouraging designers to discuss this aspect of instructional design.

Comparison of Graduates and Beginning Students. Figure 3 shows the summed lengths of protocol segments for subproblems for the designers who had graduated from the STEP program and the new students in the program. The distributions of work on the different subproblems were quite similar. Overall, the graduates' protocols included more work on the Monitor, Determine Subject and Non-Design subproblems. As we will show later, these differences were largely due to one individual in each case.

First vs. Second Design Task. Figure 4 shows the lengths of subproblem segments summed across designers on the tasks they did first and second, respectively. In general, the first designs were longer than the second ones, and designers included more of each subproblem on the first task. The relative amounts of work on the different subproblems on the two designs were similar. The first task was characterized by much more work on Determine Content and slightly less work on Determine Timing, Determine Task, Clarify Subject and Content-Relevant Non-Design. But in general, the relative amounts of work on the different subproblems on the two designs were similar.

Comparison of Principles and Operations Tasks. Figure 5 shows the profiles of subproblem segments for the Principles and Operations tasks, which were similar. The major difference is that designers worked more on the Determine Content and Monitor subproblems in the Principles task. As stated previously, the high level of monitoring can be attributed mainly to the behavior of one designer, who did the Principles task first. The main conclusion to be drawn from these data is that when designing to teach scientific principles, more work was done regarding the content of instruction than when designing to teach the operation of the vehicle, although work on content was dominant among subproblems for both the principles and operations tasks.

Individual Patterns of Subproblem Work. The pattern of allocation of work across subproblems, aggregated across tasks and groups of designers, is quite consistent. This overall pattern described earlier was consistent across individual designers, as well, with a few exceptions. Figures 6a and 6b divide the designers

Figure 3

Subproblem Lengths
Across Tasks, By Group

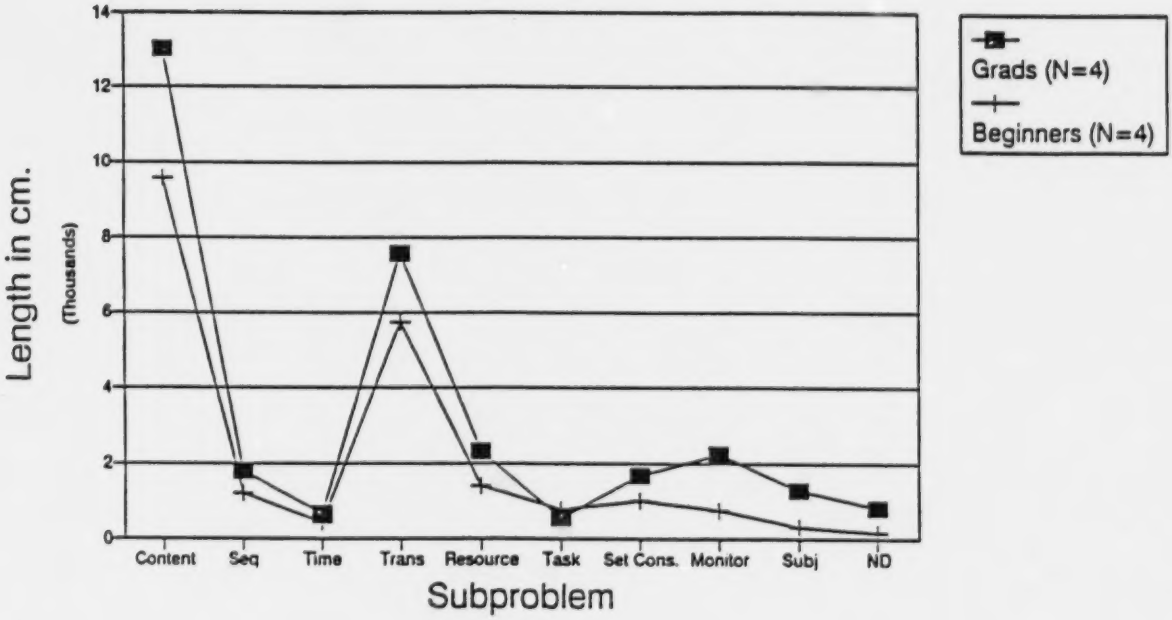


Figure 4

Subproblem Lengths
1st and 2nd Designs, Across Designers

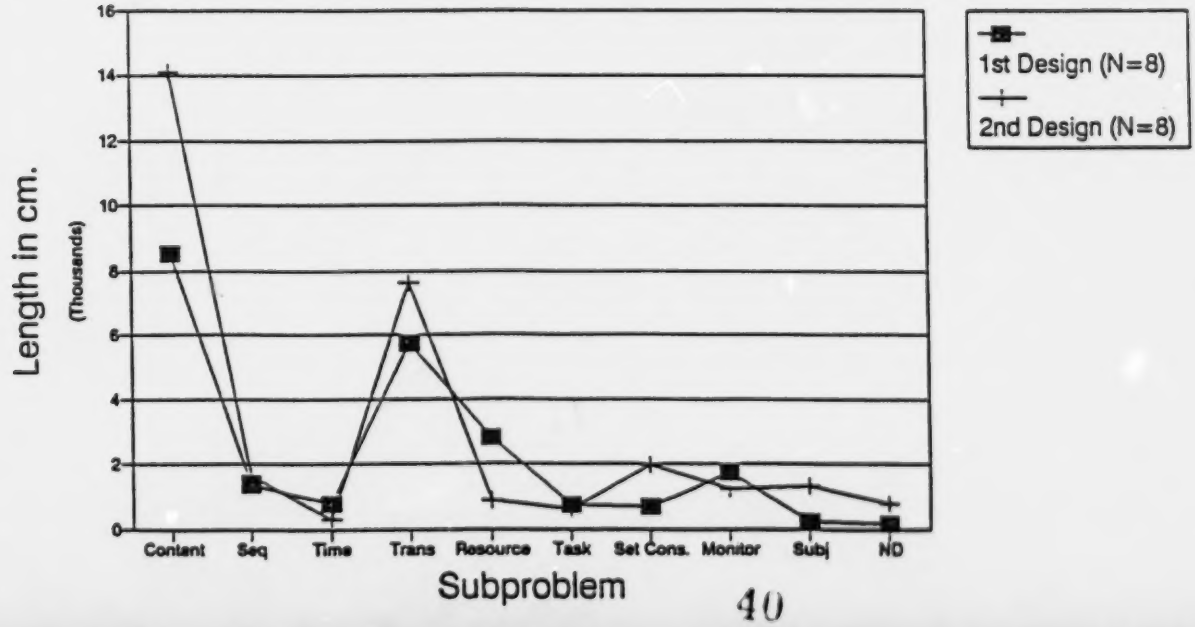
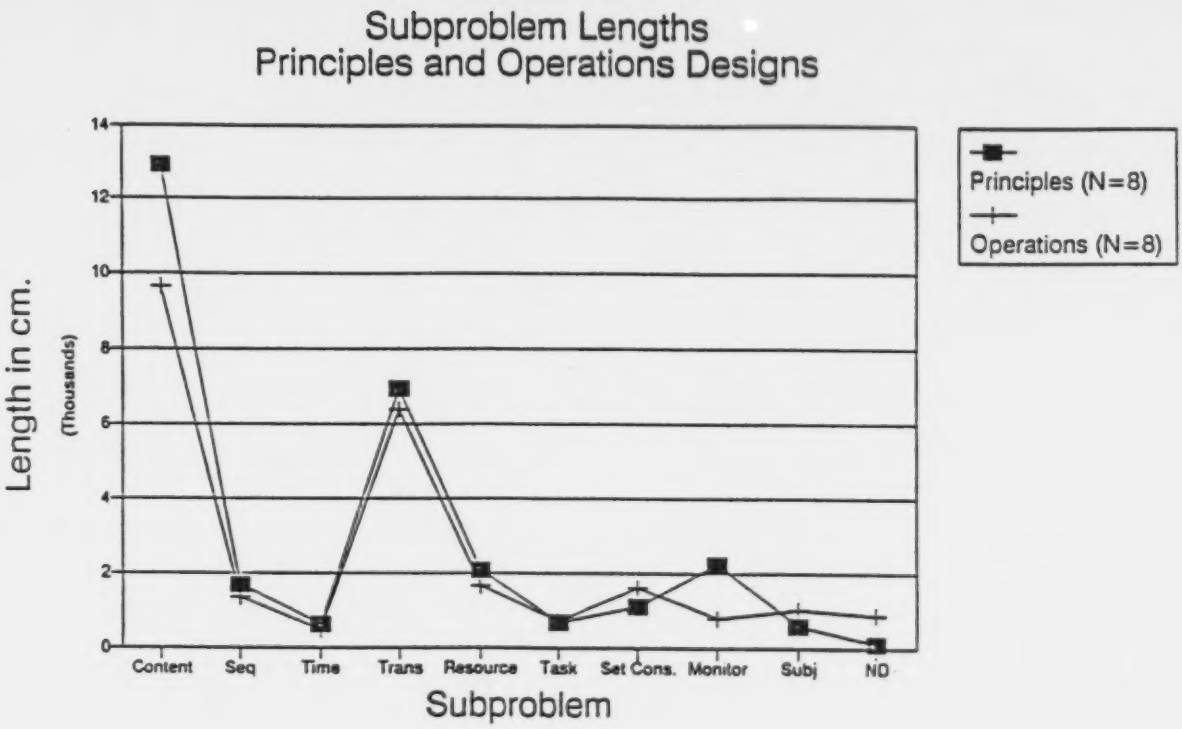


Figure 5


Subproblem Lengths
Principles and Operations Designs
Length in cm.
(Thousands)
14
12
10
8
6
4
2
0
Content
Seq
Time
Trans
Resource
Task
Set Cons.
Monitor
Subj
ND
Subproblem
Principles (N=8)
Operations (N=8)

into two groups according to their total amount of work on all of the subproblems in their protocols.

Figure 6a shows the subproblem profile for the four designers with the smallest total subproblem lengths, again compared to the average profile. Designer N2A worked much less on the Determine Content and Determine Transaction subproblems than the average. Designer N4A had a markedly different profile. For N4A, the main subproblem was Determine Instructional Transaction. He worked on Determine Content about half as much as Transaction, and he worked on the other subproblems very little. Designer N3B followed the average pattern very closely. Designer G1A also followed the average pattern, but worked much more than average on Determine Instructional Resource subproblems.

Figure 6b shows the subproblem profiles for the four designers with the greatest total subproblem lengths, and compares them with the average profile for all designers (adapted from Figure 2a). We see here that, with the exception of G3A's greater amount of work on the Monitor subproblem, G2B's greater amount of work on the Determine Subject and Non-Design subproblems, and G4B's greater amount of work on all subproblems, these profiles coincide fairly well with the overall profile.

Patterns of Work on Subproblems Over Time. This section describes profiles of work on subproblems across episodes. These profiles show the relative lengths of subproblems within episodes and the order of subproblems between episodes. Designers exhibited two major patterns, which we call the prototypical pattern and the alternative pattern. Below, we describe the prototypical pattern and some variations of it. Then, we describe the alternative pattern. Finally, we describe two unique problem-solving sequences that do not fit any of the other patterns.

Prototypical pattern. In the prototypical pattern, the designers spend one or two short episodes at the beginning of the problem clarifying the task that the interviewer has presented. The main part of the designs are characterized by a major emphasis on Determine Content across episodes, with brief bits of Determine Sequence within each episode. The designers sometimes specify some instructional transaction or, less often, instructional resource while proposing the content. Also, the designers sometimes comment on their progress on the design, as indicated by the presence of the Monitor subproblem.

Figure 6a

Subproblem Lengths Across Tasks
Comparing Ss w/ Shortest Designs to Avg

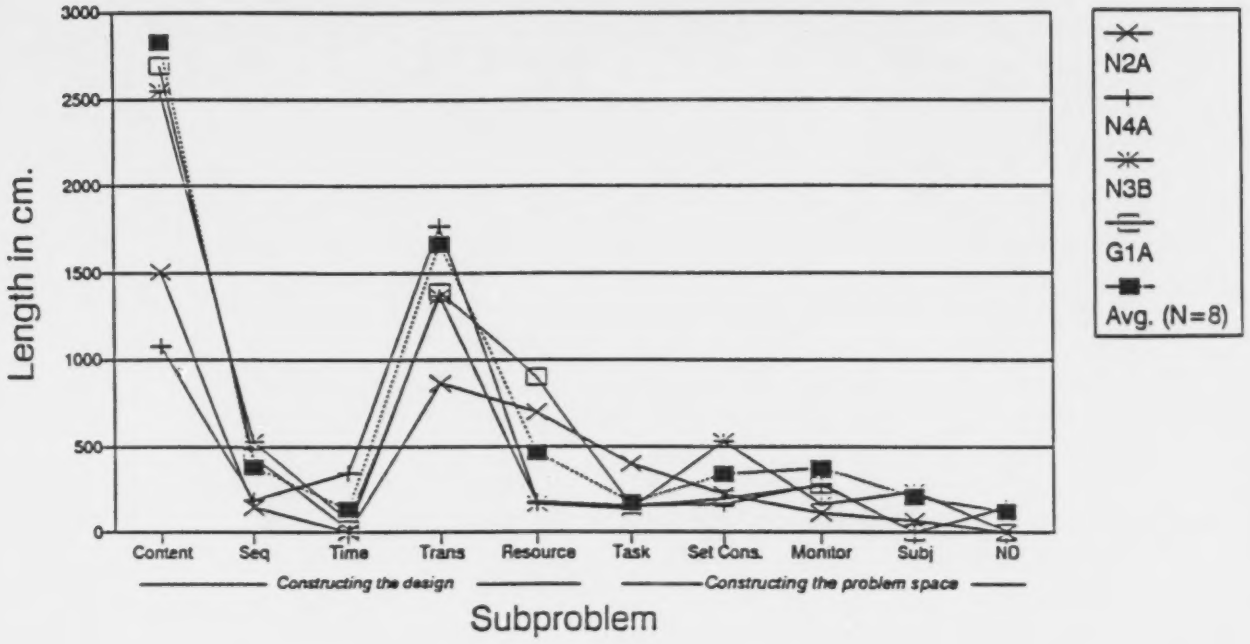
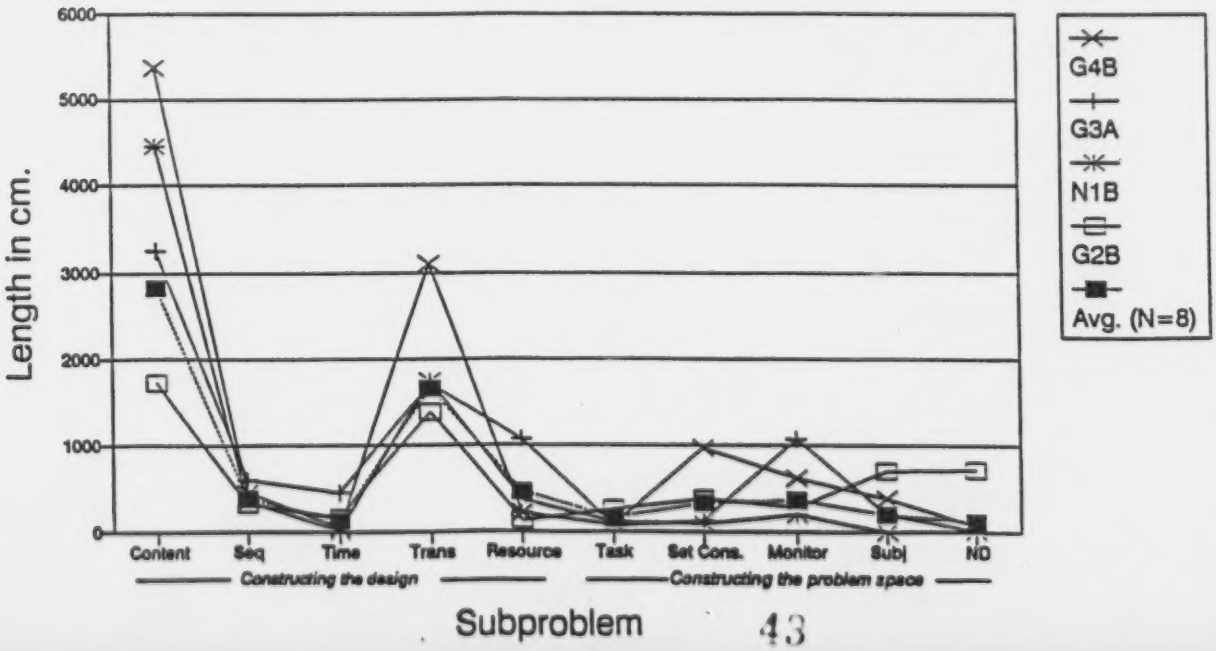


Figure 6b

Subproblem Lengths Across Tasks
Comparing Ss w/ Longest Designs to Avg.



The following excerpt from G1A's transcript shows four of these subproblems occurring together. The dominant subproblem is Determine Content. Determine Sequence is underlined; Instructional Transaction is printed in boldface; Monitor is in italics.

> Then, have them learn about the switches then, at that point, showing how you switch energy from one place to another. And again, you have to get into a little bit of theory about circuits. Have to teach them about having circuits, the completeness of circuits. *And so we'd have that covered; they'd understand the theory of switches.* Then, so we wouldn't have to teach them technically, "turn this switch on; turn this switch off," et cetera. They would be able to solve that for themselves. **And they'd be given various problem-solving exercises. You know, "start flipping switches and see what happens" sort of thing. And have some sort of safety, you know, somebody in the way of being able to keep from plowing down somebody.** But that they can see what the results are of the different combinations of switches. [G1A, Operations, Episode 7]

Two clear examples of the prototypical problem-solving pattern are shown in Figures 7 and 8 (Designer N1B on the Principles design and Designer G1A on the Operations design, respectively). In these figures, the lengths of the horizontal bars are proportional to the amount of each subproblem that occurred in each episode. Each episode was characterized according to the main subproblem on which the designer worked during it. These main subproblems are represented in the figures by wide bars that run the length of the episodes. The amount of other subproblems that occurred within each episode are represented by narrow bars.

Late in the main design task, the designers often switched to Instructional Transaction, or sometimes Instructional Resource, as the main subproblem. However, Content and Sequence continued to occur along with Transaction and Resource. After this point, the designers sometimes alternate between Content and Transaction as the dominant subproblem but, whichever was dominant, the same set of subproblems (Content, Sequence, and Transaction or Resource) continue to occur together.

Figure 7
Subproblem type and duration as a function of episode number for transcript N1B-Principles.

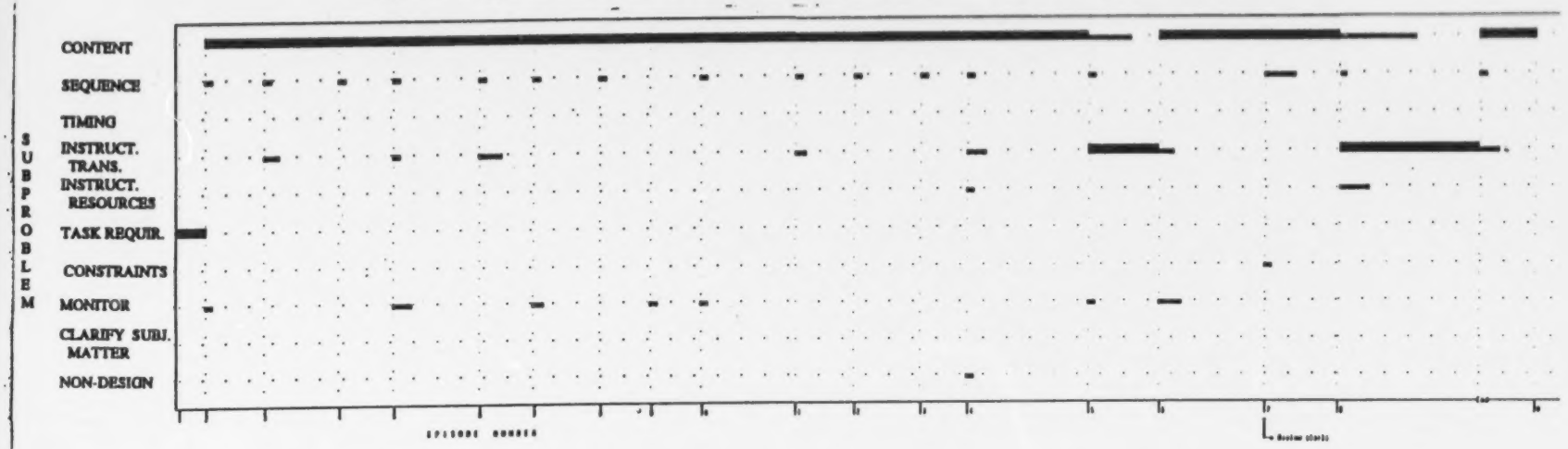
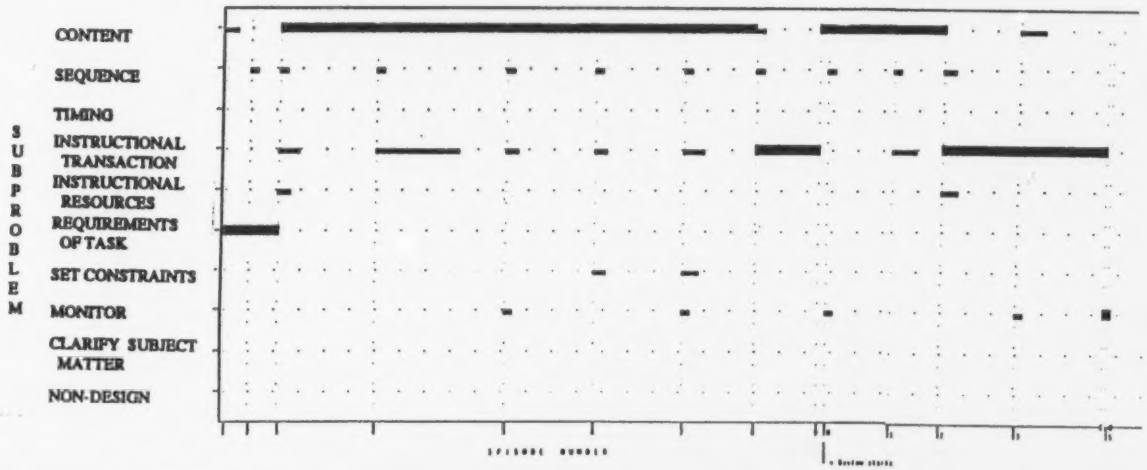


Figure 8
Subproblem type and duration as a function of episode number for transcript G1A-Operations.



During the review task, the designers were asked to discuss a structured sequence of topics. The protocols typically reflect this sequence, focussing first on Content (again with accompanying Sequence), and then switching to Transaction and/or Resource.

This prototypical problem-solving pattern characterized 6 of the 16 designs, representing work from one-half of our designers: participants N1B (both designs), N2A (both designs), N3B (Principles design), and G1A (Operations design). Graphs of the subproblem sequences for N2A, N3B (Principles), and N1B (Operations) appear in Appendix IV.

Variations on the prototypical pattern. The protocols of Designers G1A and G3A on the Principles task and of Designer G4B on the Operations task exhibit some similarities to and differences from the prototypical pattern. All three of these protocols share a strong emphasis on Determine Content. G1A's protocol (see Figure 9) is most like the prototype. In fact, beginning with episode 11, G1A's subproblem sequence fit the prototypical pattern. However, prior to that, the pattern was somewhat different. In the first ten episodes (about one-third of the protocol), there was an overall shift from emphasizing Content and Sequence to emphasizing Instructional Transactions, but in episode four, G1A went through a fairly long segment of determining the sequence, and in episode six, G1A went back to clarify the task again.

Designers G3A and G4B present more complex patterns. Again, there is strong emphasis on determining content, but they tend to work on many subproblems within each episode. Figure 10 shows G3A's Principles subproblem sequence. (For ease of exposition, we divide this protocol into five sections of approximately equal length: four sections for the main design, plus the review. These divisions are shown on separate pages of the figure.) Pages two and three (middle of the main design) look similar to the prototypical pattern: the major emphasis is on content, with small blocks of other subproblems. The main difference between this protocol and the prototypical one is that G3A adds Determine Timing to the set of subproblems worked on. G3A also includes a few short episodes in which sequence, timing, or monitoring are the main focus.

Going back to the first page of the main design, G3A switches between dominant subproblems: from Resource, to Content, to Timing, to Transaction, back to Content, back to Resource, back to

Figure 9
Subproblem type and duration as a function of episode number for transcript G1A-Principles.

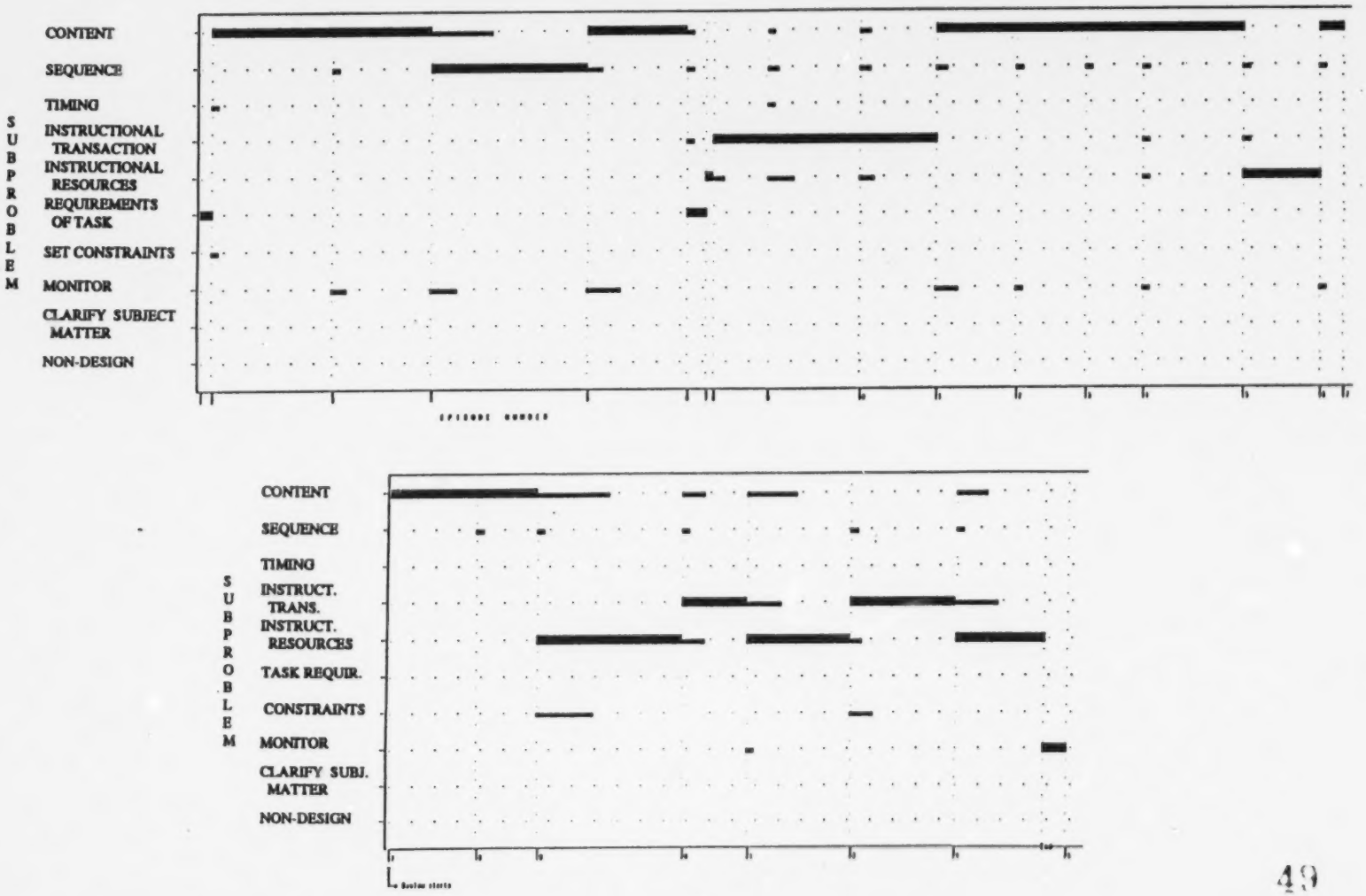
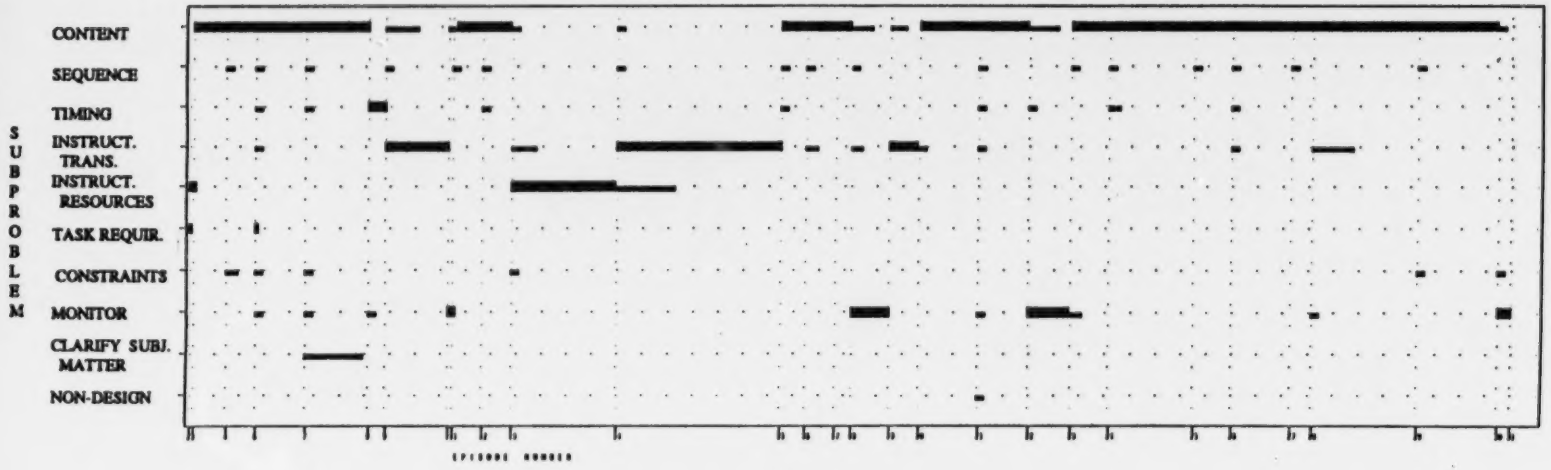
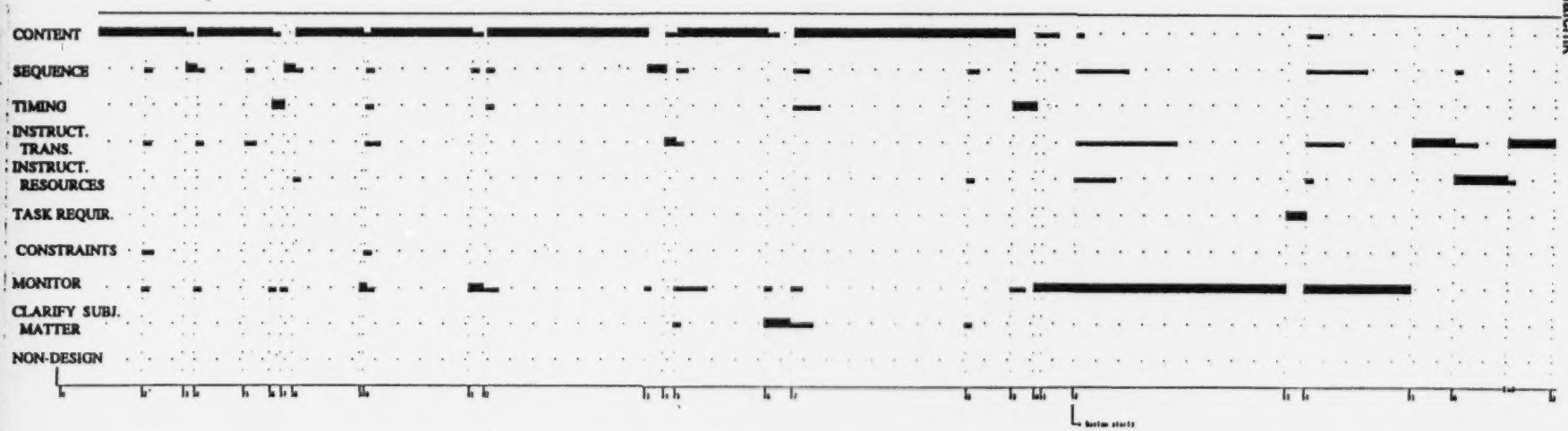


Figure 10

Subproblem type and duration as a function of episode number for transcript G3A-Principles.





Transaction, and back to Content again. During the last part of G3A's main design (page four of the figure), the major emphasis is on content (with some attention paid to sequence and timing), but he also includes a section of clarifying the subject matter (EP46), and ends with two episodes of monitoring. G3A's review (page five of the figure) focuses mainly on monitoring, and ends with episodes about transactions and resources.

G4B's (Operations) subproblem sequence shows a similar general pattern, though the specific subproblems differ (see Appendix IV). Overall, the prototypical pattern and variations on it accounted for 9 of the 16 designs, and were used at least once by six of our eight designers.

Alternative pattern. Apart from the prototypical sequence with its heavy emphasis on content, the other major pattern that designers employed contains a balance of Determine Content and Determine Transaction; the two subproblems are emphasized about equally during problem-solving. This alternative sequence is also distinctive in that designers usually discussed instructional transaction and content independently, rather than together, as in the prototypical pattern.

The alternative pattern was seen in five designs by four of the designers: N4A (both designs), G2B and G4B on the Principles design, and N3B on the Operations design.

Designer N4A subproblem sequences are shown in Figures 11 and 12. The first half of N4A's main Principles design (Figure 11-1) focuses primarily on Instructional Transactions, with some Timing and Content, and regular monitoring. A section in the middle of this design (Figure 11-1, episodes 12-16) looks something like the prototypical pattern with the addition of Determine Timing. Episodes 17 through 20 go back to Timing and Content. N4A's review (Figure 11-3) focussed almost entirely on Transactions. N4A's Operations design (Figure 12) switched from an initial emphasis on Content to a major emphasis on Transactions. Subproblem sequences for the other designs are in Appendix IV.

Other sequences. The operations designs of G3A and G2B followed different patterns than those described above. G3A's dominant focus during the main design (see Figure 13) was on timing and resource, with some transaction. During the review, G3A focussed first on content, then on transaction.

Figure 11
Subproblem type and duration as a function of episode number for transcript N4A-Principles.

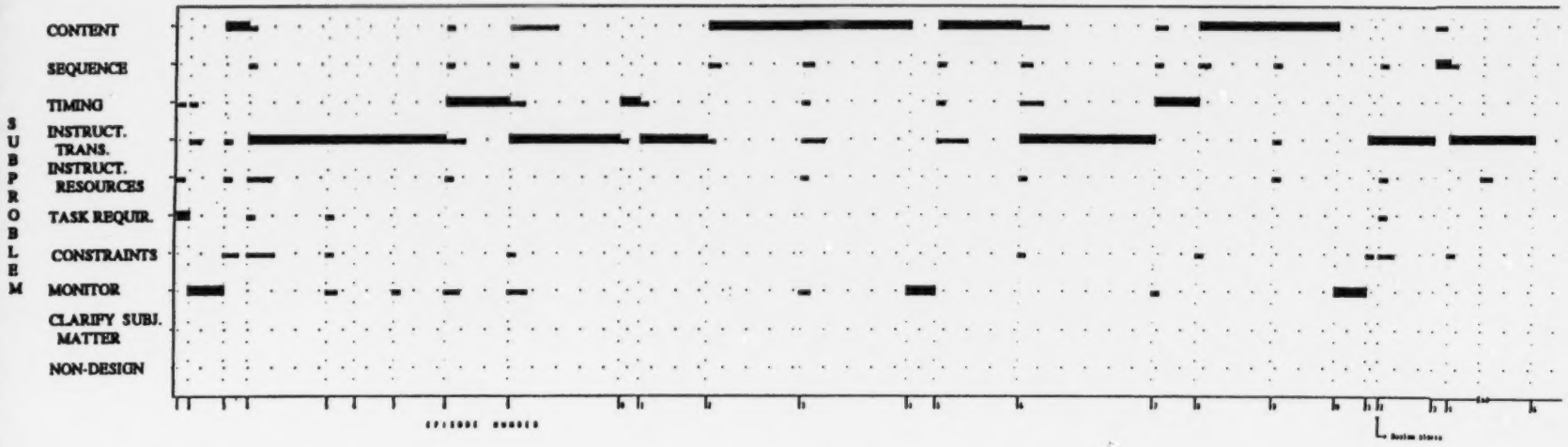


Figure 12
Subproblem type and duration as a function of episode number for transcript N4A-Operations.

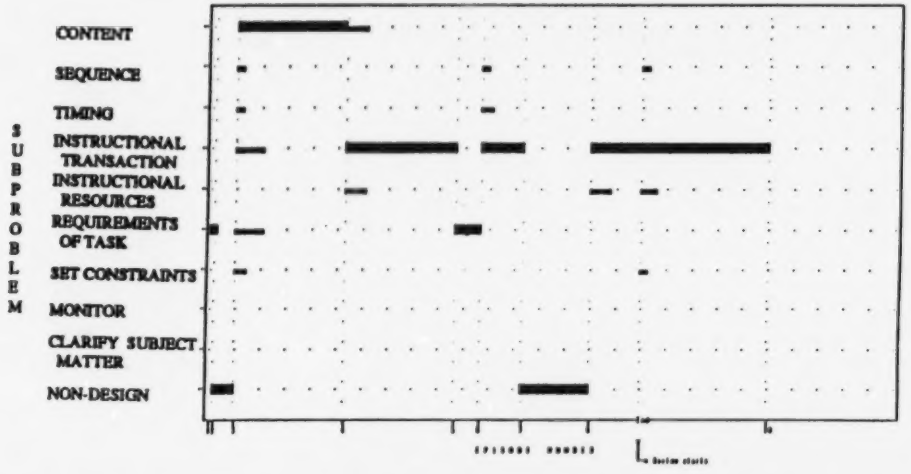


Figure 13

Subproblem type and duration as a function of episode number for transcript G3A-Operations.

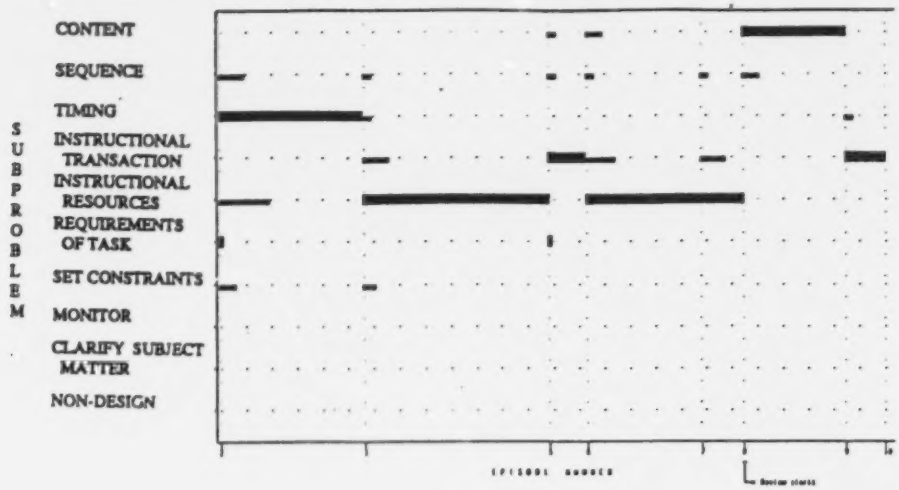
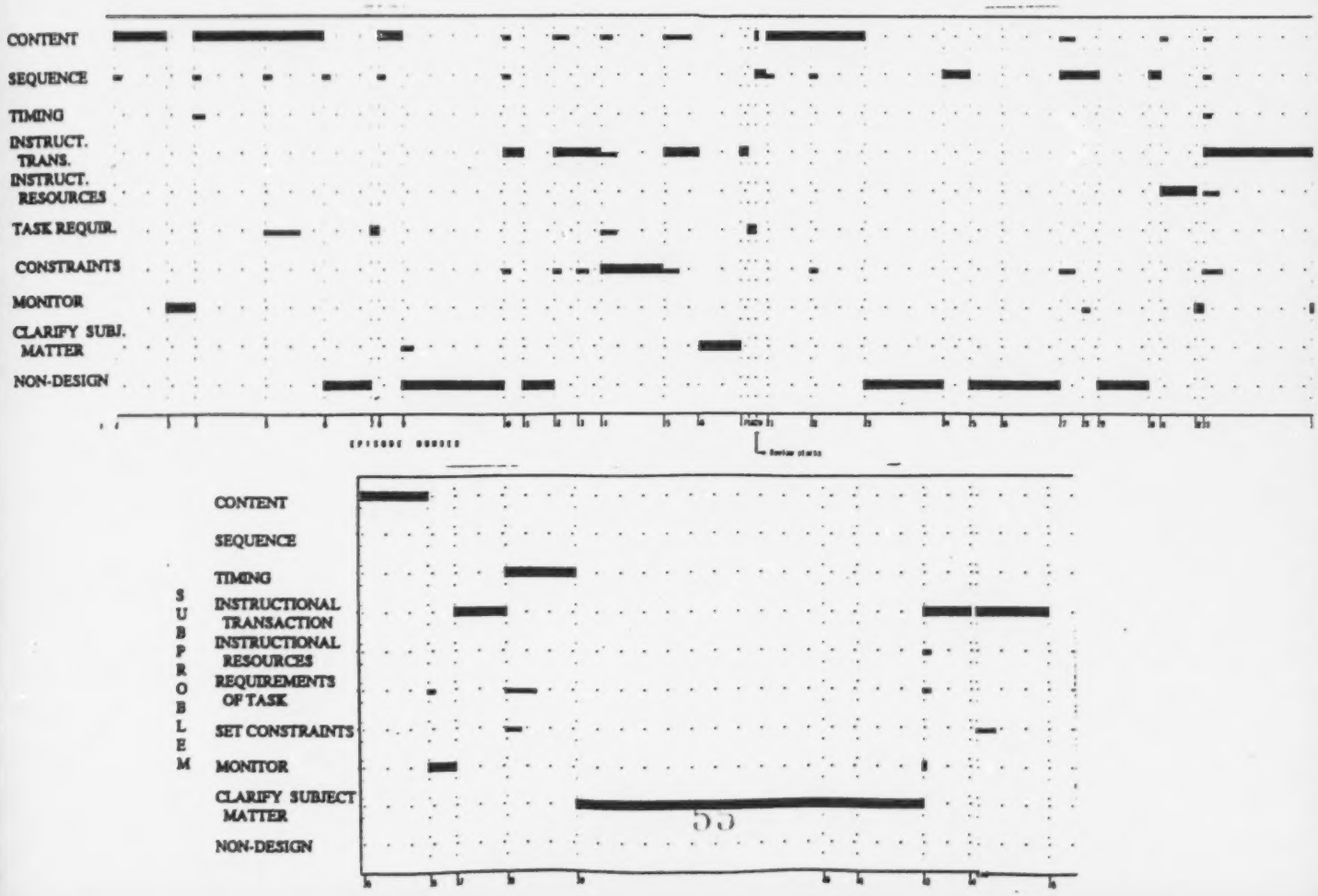


Figure 14

Subproblem type and duration as a function of episode number for transcript G2B-Operations.



G2B (Operations) exhibited an apparently disorganized problem-solving style. He tended to focus on one or two subproblems at a time, but bounced between a variety of subproblems (Figure 14). The most outstanding features of G2B's Operations design was the amount of time spent in content-relevant non-design activity (over 18% of the total subproblem length), and the fact that he spent a large chunk of time (over 15% of the total) at the end of the review clarifying the subject matter of the instruction.

Conclusions about Subproblem Sequence. Two major patterns of problem-solving are seen within the subproblem sequences of these designers. The first emphasizes content (with embedded sequence), and later includes instructional transaction and/or resource. The second focuses equally on transaction and content, but tends to treat them separately. One designer (G3A, Operations) emphasized timing, resource and transaction, with relatively little content. Most designers tended to focus on one or two subproblems at a time, but others preferred to juggle many at once.

The main conclusion we draw from these data is that instructional design is a multidimensional task, with components that can be worked on in a variety of orders. The major dimensions are determining the content and the instructional transactions, but some designers also choose to focus on timing and instructional resources. Sequencing is typically performed in conjunction with proposing content or transactions, but it can occur independently, after the substance has been proposed.

Knowledge Types

The lengths of protocol segments coded as being based on each knowledge type were recorded for each episode.

Overall Use of Knowledge Types. The distribution of segment lengths across knowledge types, summed over designers and tasks, is shown in Figure 15. The most frequently coded category was Teach This, which included segments that were inferred to rely on knowledge of the subject matter to be taught and knowledge or opinions about the importance or difficulty of that subject matter for the instructional purposes of the unit. This means that the greatest amount of design work relied on knowledge that was in the intersection of the general category of pedagogical content knowledge, rather than in pedagogical or in content knowledge, according to our definitions. Perhaps the most notable feature of the distribution is the relatively small amount of the design work that was inferred to rely on knowledge in the general pedagogical category, including general knowledge about teaching or learning, instructional resources, and the characteristics of students.

Graduates vs. New Students. Figure 16 shows the distributions of protocol segments across knowledge types separately for designers who had graduated from the STEP program and those who were new students. The overall patterns are very similar, including the small amounts of the protocols attributed to pedagogical knowledge categories.

First vs. Second Tasks. The distributions across knowledge types for the designers' first and second tasks are shown in Figure 17. Again, the patterns are very similar, with the differences in these aggregate distributions easily attributable to the fact that designers had longer protocols for the tasks they performed first.

Principles vs. Operations Instruction. Figure 18 shows the distributions across knowledge types for the two design tasks involving principles and operation of the vehicle. There apparently were two differences in the knowledge used in the two tasks. First, in the category of content knowledge, more of the protocols in the Principles task used general knowledge of science, and less of the Principles protocols used knowledge about the VST device. This difference would be expected; it merely reflects the difference in the content of the tasks.

Figure 15

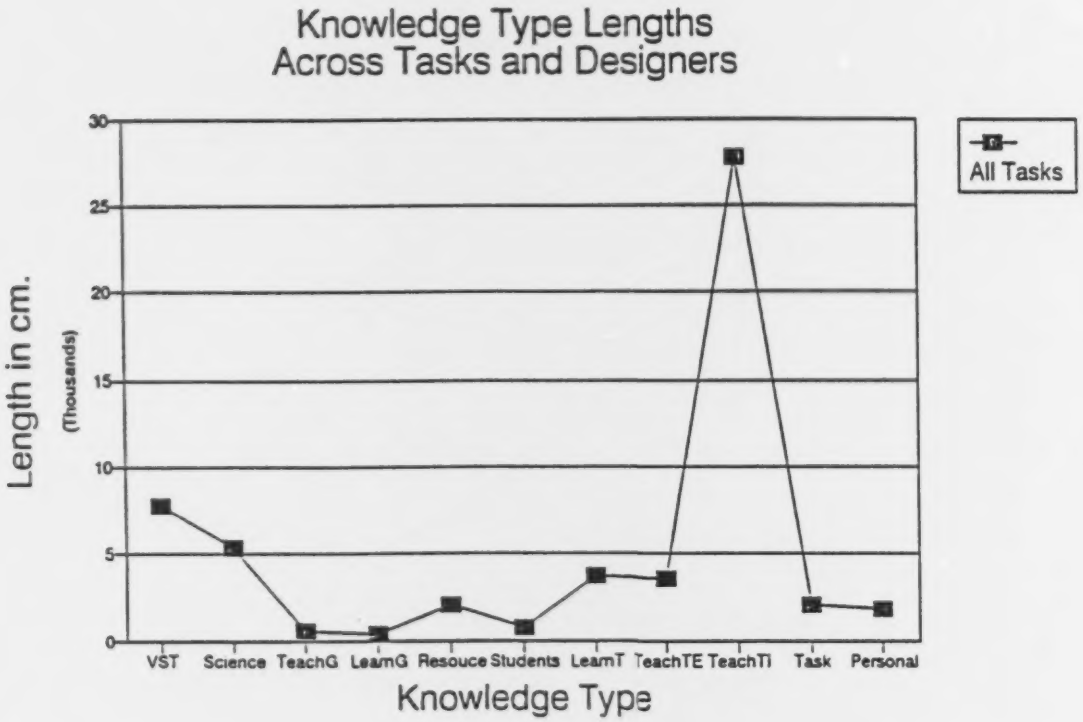


Figure 16

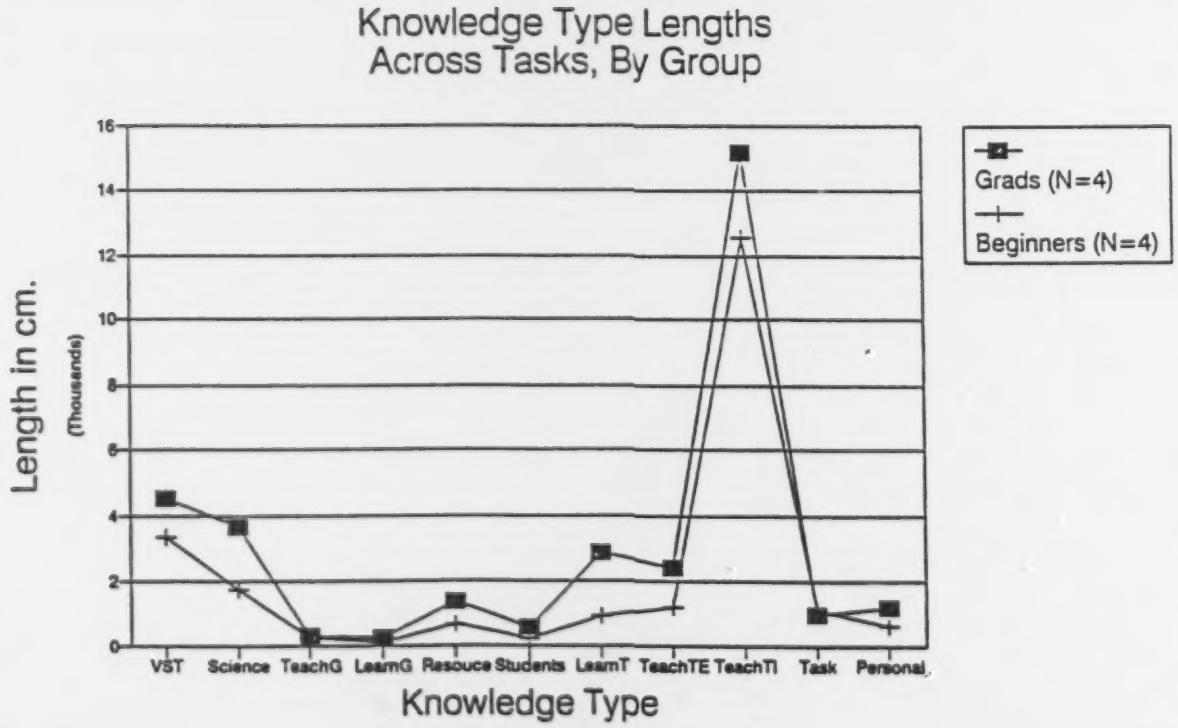


Figure 17

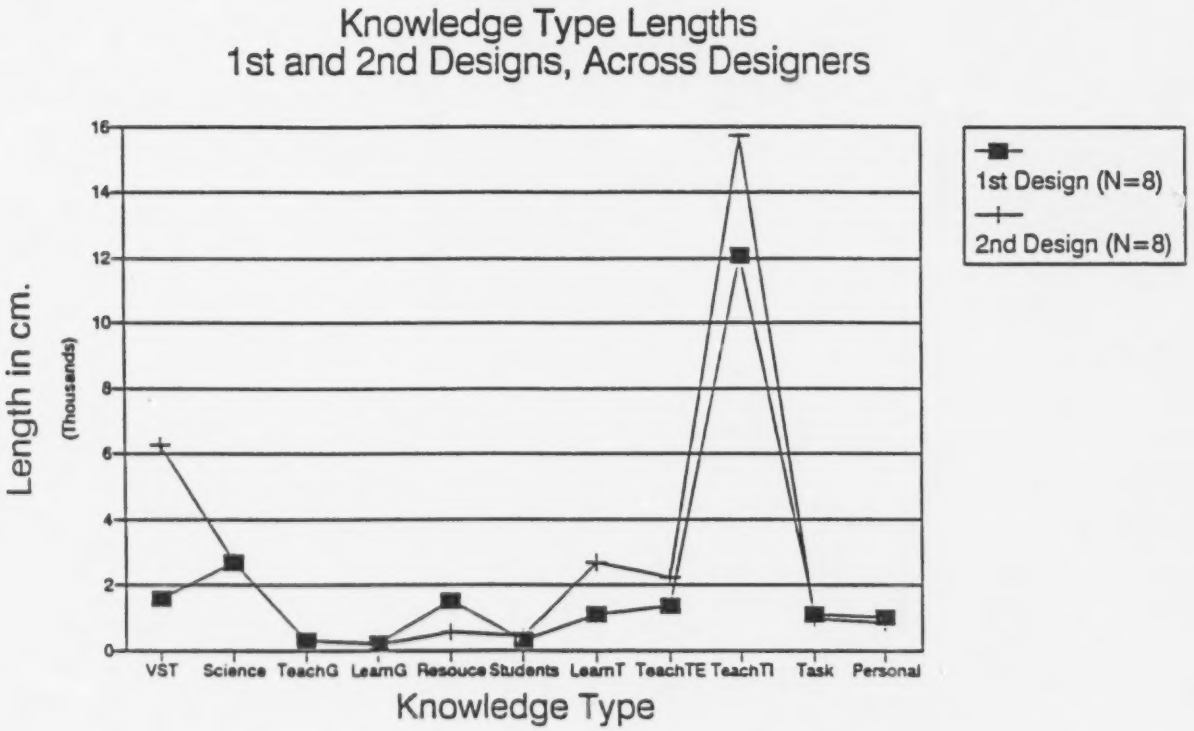
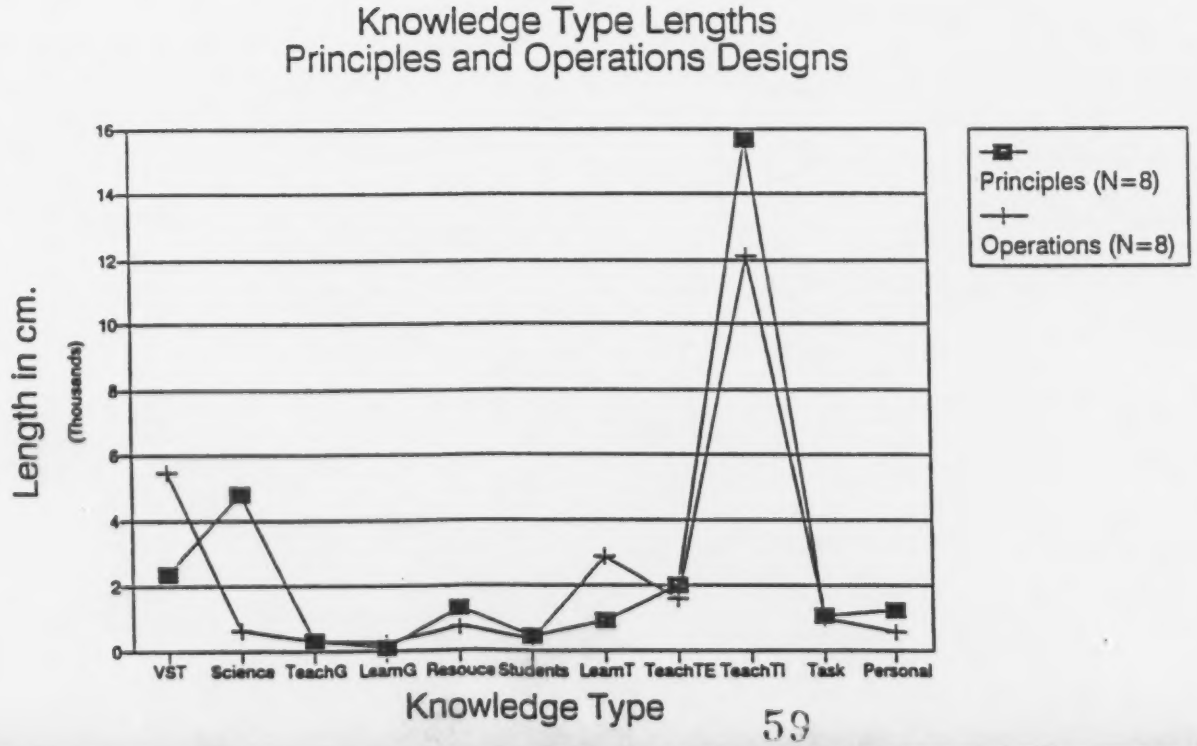


Figure 18



The other apparent difference is in the general category of pedagogical content knowledge. More of the protocols in the principles task used knowledge in the Teach This category, while less of those protocols used knowledge coded as Learn This. This difference is not as tautological as the difference between VST and Science knowledge, but it is also quite understandable. Designers who used more knowledge about learning in the Operations task gave considerable attention to properties of the tutorial in which they had learned about the VST vehicle. It might be generally true that in designing instruction about material that a designer has recently learned, the materials and experiences associated with the person's learning would play a relatively greater role. On the other hand, the content of the Operations task probably was more constrained for the designers than the content of the Principles task; therefore, decisions about what to teach played a smaller role in the Operations instruction, and there was less use of knowledge and opinions about the importance of particular items of content.

Figures 19a and 19b show the knowledge type distributions for individual designers on the Principles task. Figure 19a has the distributions for the designers who designed the Principles instruction first, and Figure 19b has the distributions for designers who designed Principles instruction second. The tendency to use more knowledge about science than about the VST characterized four of the six designers; more of N1B's protocol was coded as using knowledge about the VST, and very little of N4A's protocol was coded as using either VST or science knowledge. The protocol of G3A contributed an exceptionally large amount of protocol to the large total that was coded as using Teach This knowledge; the other designers all contributed between 1000 and 2000 units in this category, and G3A's protocol included over 4000 units.

Figures 20a and 20b show the individual distributions for the Operations task, in their first or second task, respectively. All of the designers except N4A contributed to the greater use of VST knowledge than science knowledge on the Operations task. The relatively greater use of Learn This knowledge in the Operations task, compared to the Principles task, was the result of two protocols: G2B and G3A. Both of these designers' protocols included a great deal of discussion of the tutorial about the VST, with comments about features that made it hard or easy to understand the

Figure 19a

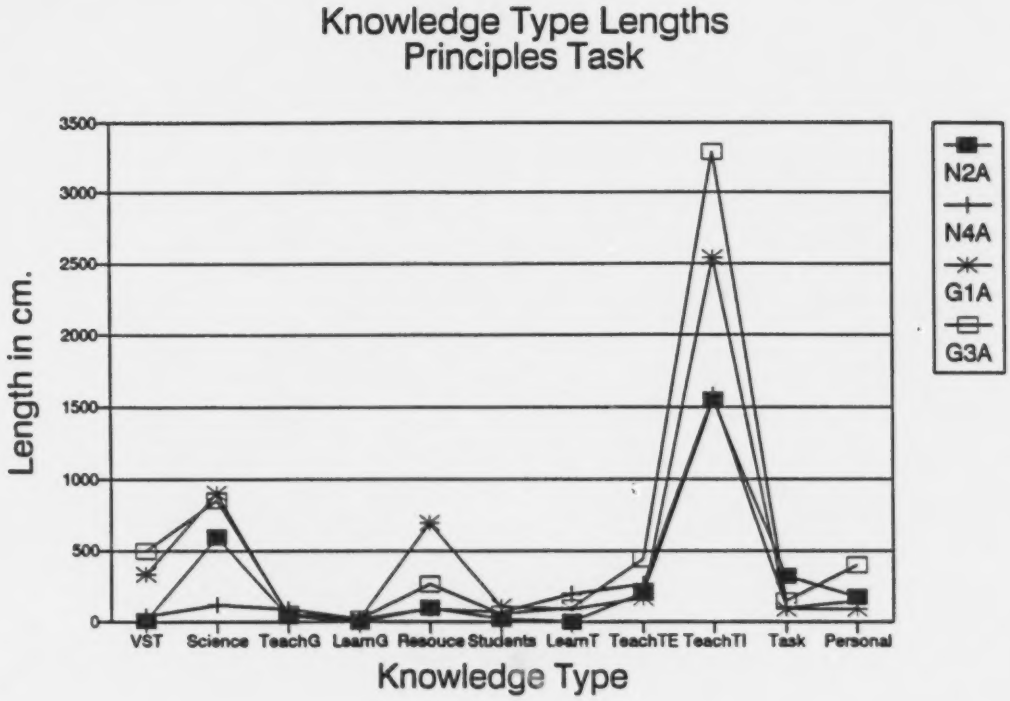


Figure 19b

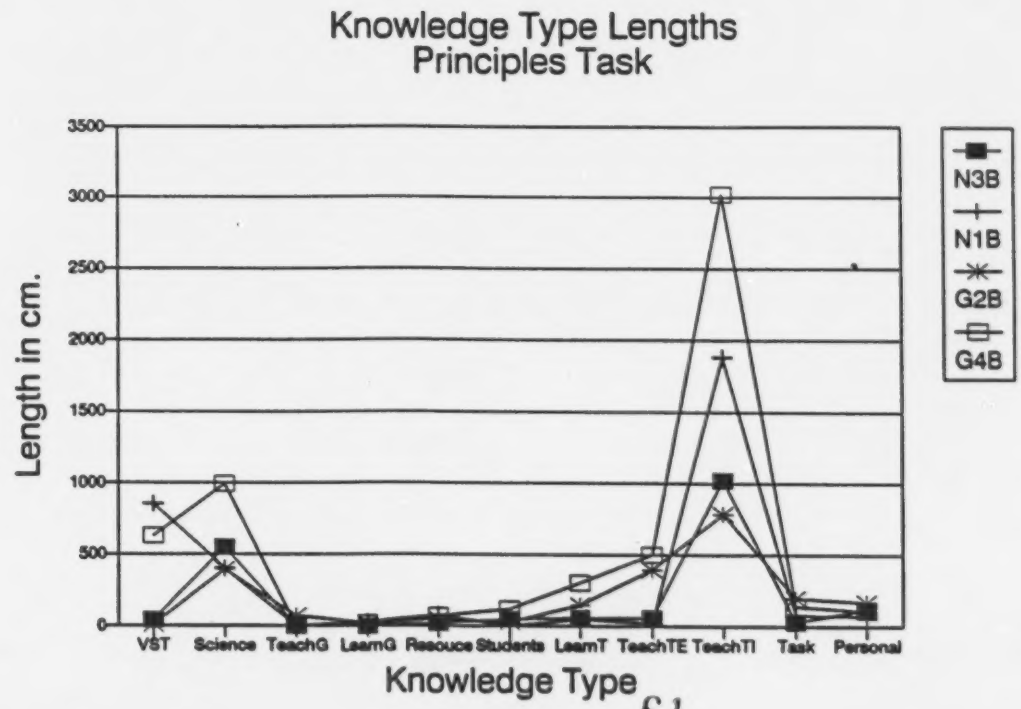


Figure 20a

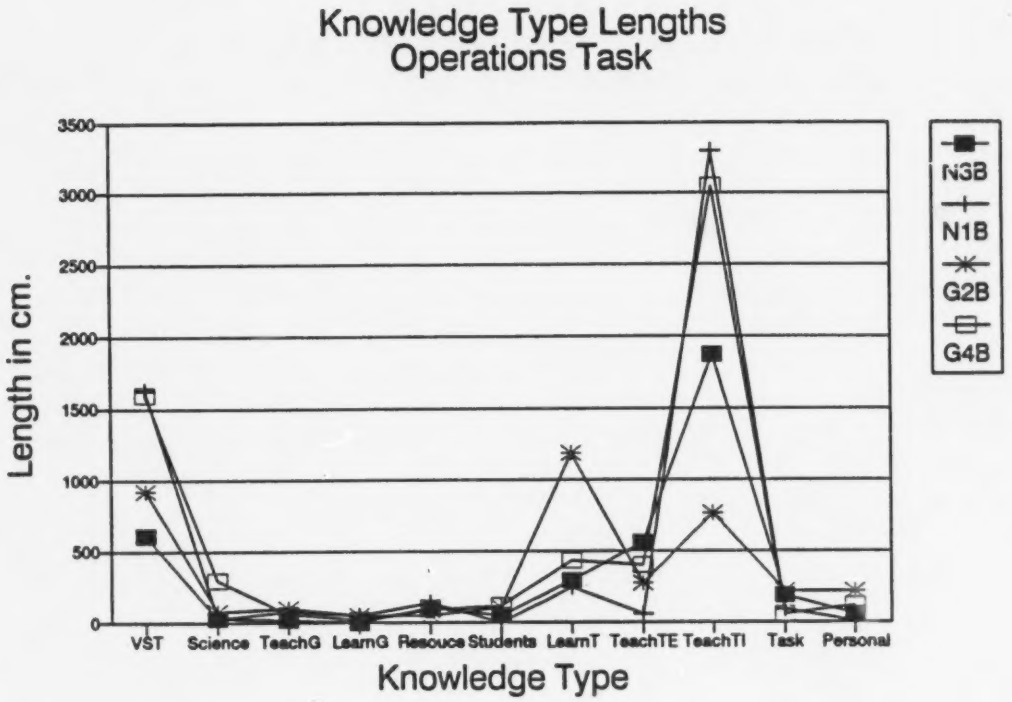
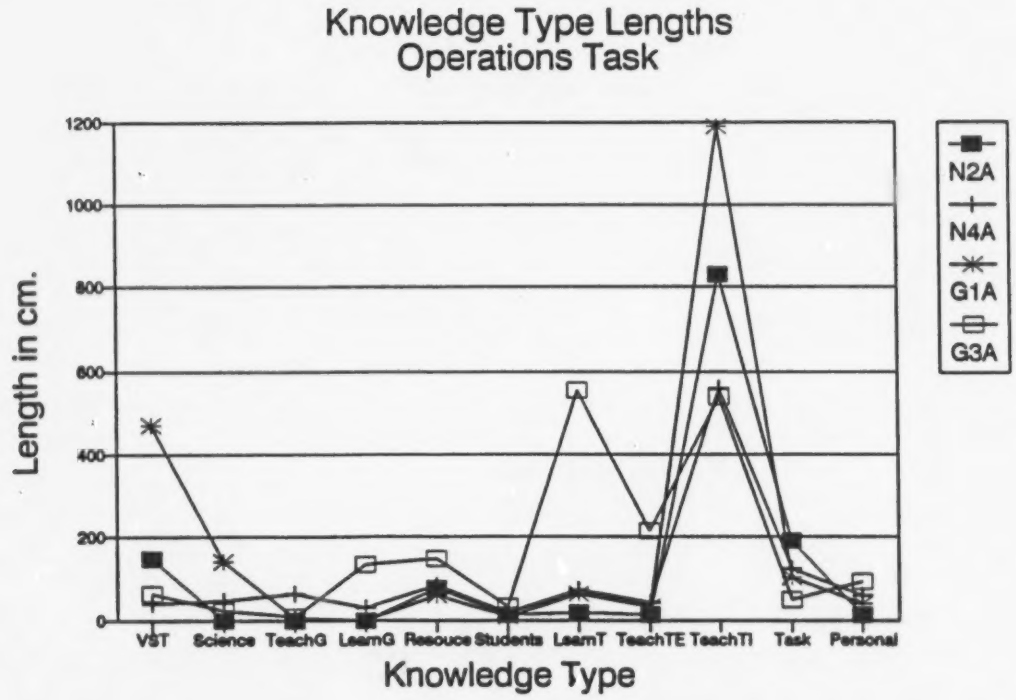


Figure 20b



material, or about what features of the tutorial would be effective in the instruction that was being designed.

Patterns of Use of Knowledge Types over Time. The typical pattern of knowledge-type use over time reflected the fact that very little use of purely pedagogical knowledge was judged to have occurred. In most of the protocols, then, the pattern of knowledge types across episodes showed concentrations of use of content knowledge and pedagogical content knowledge across all the episodes. Figure 21 shows a quite typical pattern, by designer N2A in the Principles task, who began with some discussion of the features of the design task, and mainly used Science knowledge and Teach This knowledge thereafter. The use of other knowledge types that did occur happened mainly toward the beginning and toward the end of the session. Figure 22 shows N2A's pattern of knowledge types for the Operations task, which was done second. Content knowledge, mainly about the VST, and Teach This knowledge were dominant at the beginning, and there was some use of knowledge about available resources along with Teach This at the end.

Another example is in Figure 23, the longer protocol of designer G3A. Recall, from Figure 10, that G3A's pattern of work on subproblems was somewhat more complex than the the typical subproblem pattern, with work on various subproblems interleaved throughout the session. G3A's pattern of use of knowledge types, however, conformed quite closely to the typical pattern of some attention to pedagogical considerations at the beginning and the end, and mainly use of content and Teach-This knowledge in the main portion of the task. Figure 24 shows G3A's pattern on the Operations task, done second. This pattern shows an unusually large amount of use of pedagogical knowledge; it was used throughout the session, rather than only at the beginning and end. Recall, from Figure 13, that this design focused mainly on instructional transactions. This focus might have been associated with the greater use of pedagogical considerations.

Graphs of the remaining patterns of knowledge-type use over time are presented in Appendix V. Each was similar in significant respects to one of the patterns we have described and illustrated. Both of N1B's designs and G1A's Operations design were examples of the typical pattern shown in Figures 21, 22, and 24. G1A's design of Principles instruction was quite typical except for inclusion of more use of knowledge and information about instructional resources.

Figure 21

Knowledge type and duration as a function of episode number for transcript N2A-Principles.

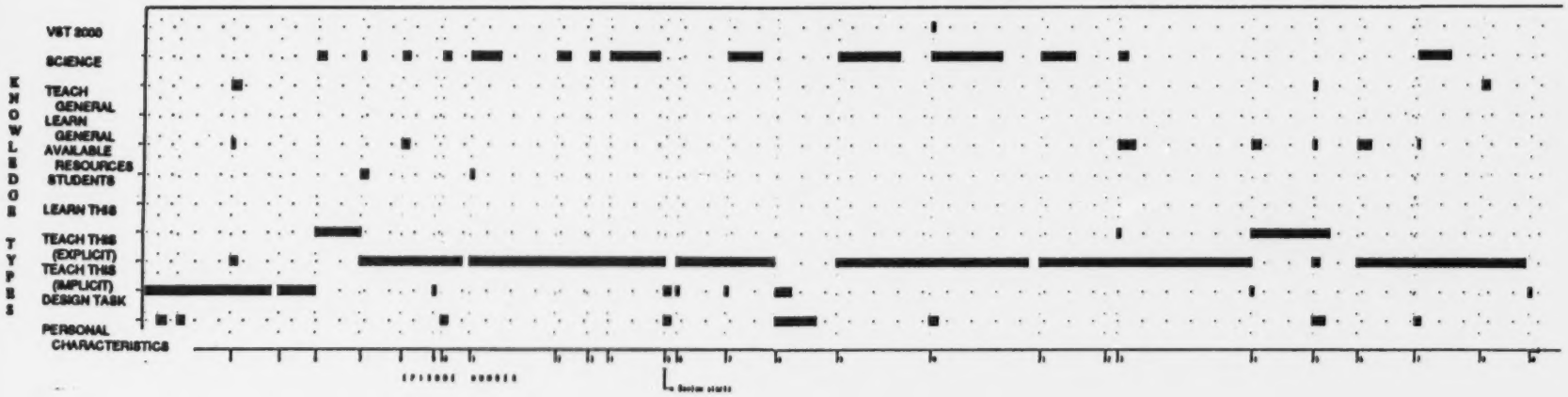


Figure 22

Knowledge type and duration as a function of episode number for transcript N2A-Operations.

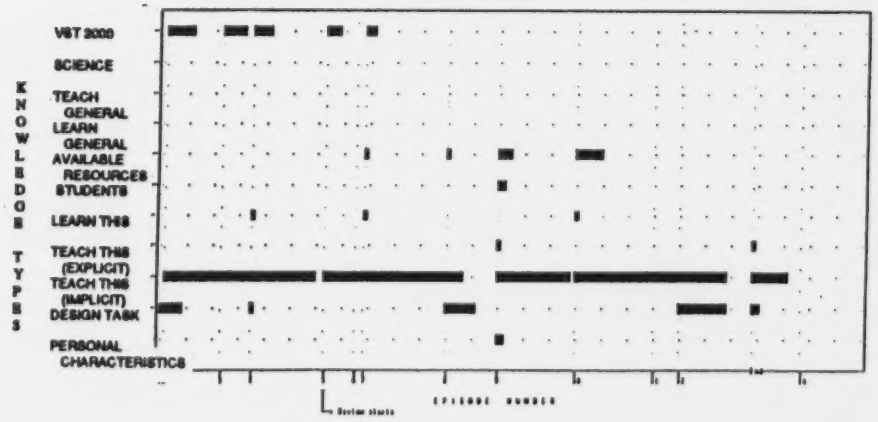


Figure 23

Knowledge type and duration as a function of episode number for transcript G3A-Principles.

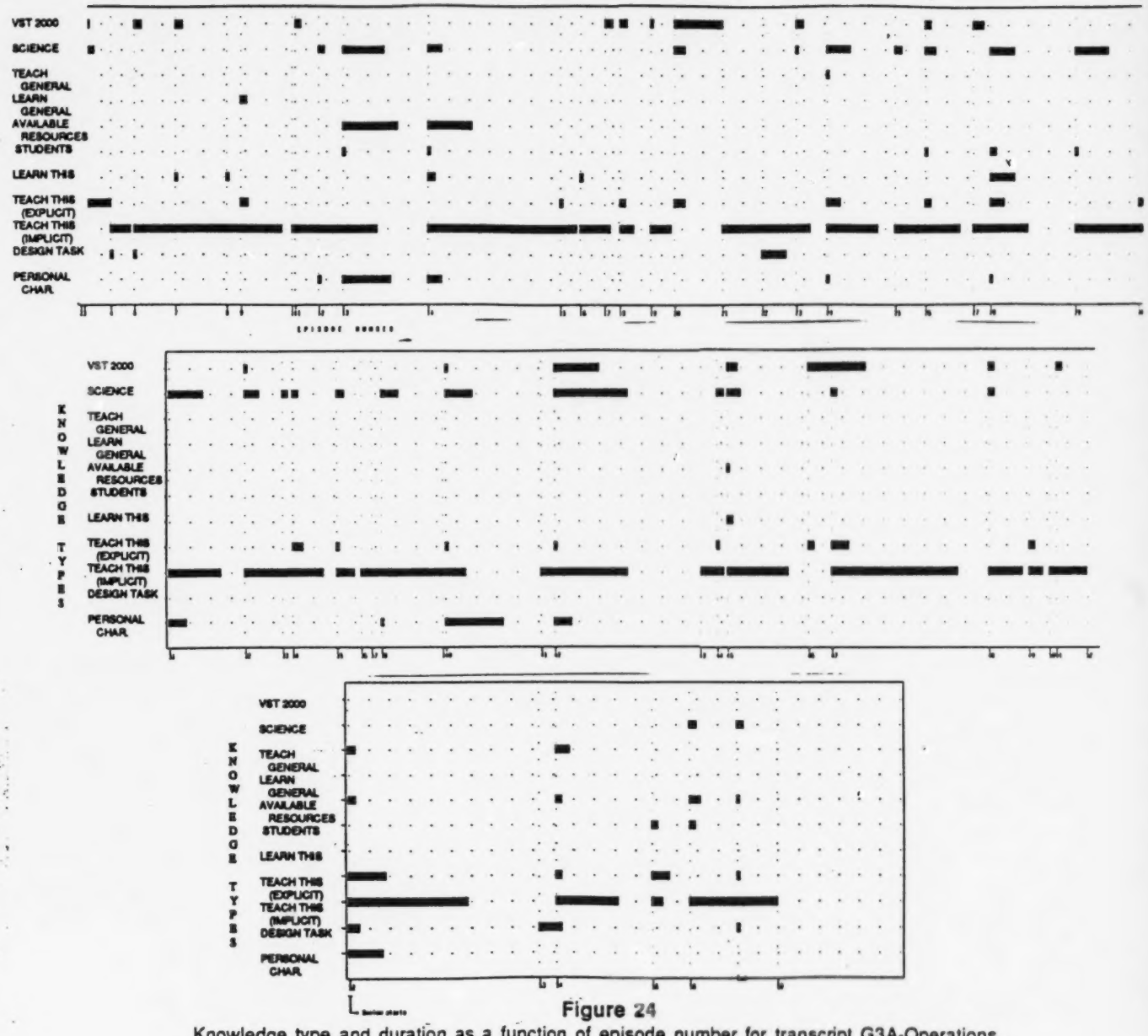
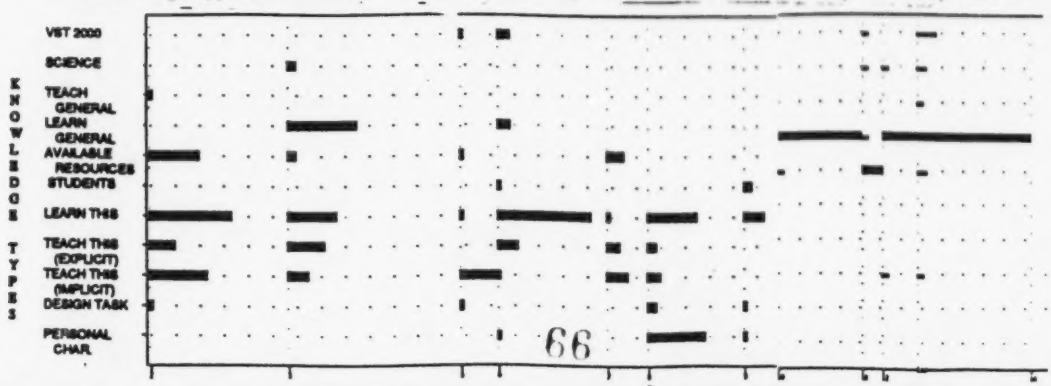


Figure 24

Knowledge type and duration as a function of episode number for transcript G3A-Operations.



Both of N4A's designs were similar to the pattern shown in Figure 24, G3A's Operations design, containing more use of pedagogical knowledge than the typical pattern, with the use of pedagogical knowledge distributed throughout the session. As in the case of G3A's Operations design, N4A concentrated more on the subproblem of determining instructional transactions, and use of pedagogical knowledge seems to have been associated with the Transactions subproblem. G2B's patterns of knowledge-type use were also similar to Figure 24, although G2B's pattern included use of a considerable amount of Learn This knowledge, involving review and reflection of the VST2000 tutorial.

Operators

The lengths of protocol segments coded for each operator were recorded for each episode as was done for subproblems and knowledge types.

Overall Use of Operators. Figure 25a presents the total length in centimeters coded for each of the five operators. These lengths are summed across designers and tasks. The Propose operator was used most in the design process, accounting for almost twice as much length in the final protocols as the meta-cognitive Recap/Reflect/Evaluate/ Monitor/Justify (RREMJ) operator. Include Information was used less than half as much as RREMJ (and a quarter as much as Propose). Modify was rarely used. Remove was used even less. Although Propose was used more in terms of total length than was RREMJ, the latter of these was used more frequently -- that is, more often in shorter segments. Figure 25b graphically presents this result. The Include Information operator occurred less than half as often as Propose, and about one-third as often as RREMJ.

Comparison Between the Main and Review Portions of the Tasks. The primary difference in use of operators is, not surprisingly, that designers use mostly Propose for the main task and mostly RREMJ for the review task. This finding is shown in Figure 26a. Overall, the use of the Include Information, Remove, and Modify operators stayed proportionally the same between the two sections of the designs. Frequency of use of RREMJ was about the same as Propose in the main section of the design, but was almost twice as much as Propose during the review section (see Figure 26b).

Comparison of Graduate and Beginning Students. Figure 27a indicates that the graduates participating in this study produced longer designs than beginning students. (Note the higher line for the graduates.) However, when the length of the designs is adjusted for by representing operator length in percentages, we find that graduate and beginning students look very similar in their profiles of operator use. Figure 27b, reveals, however, that there is a difference in pattern of operator use between the two groups in terms of frequency.

Figure 25a

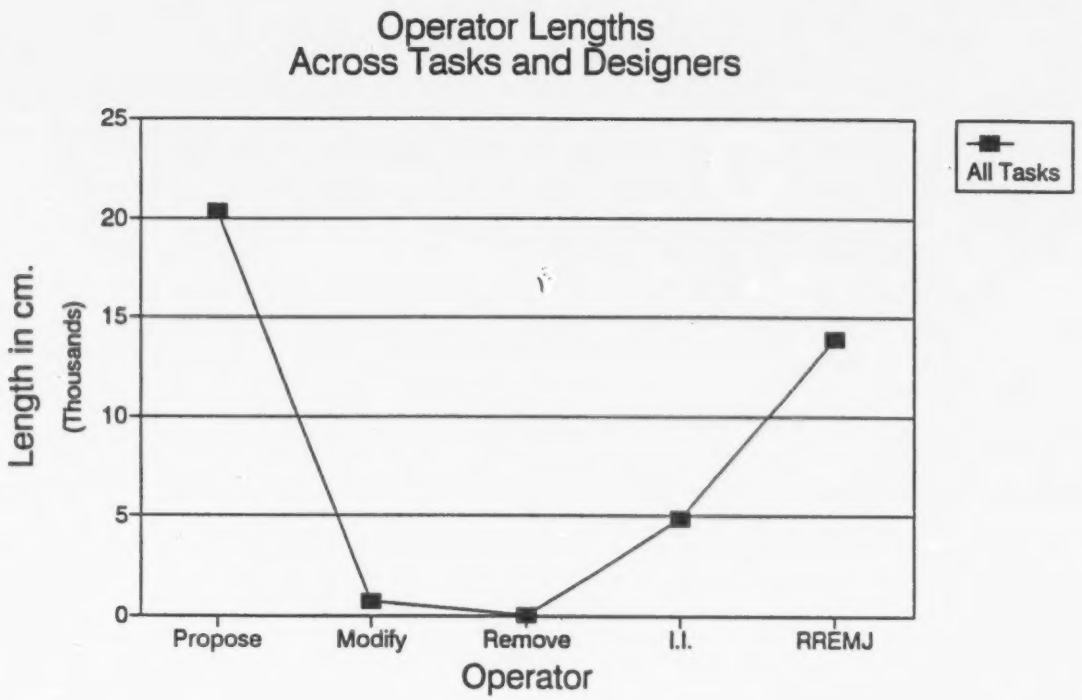


Figure 25b

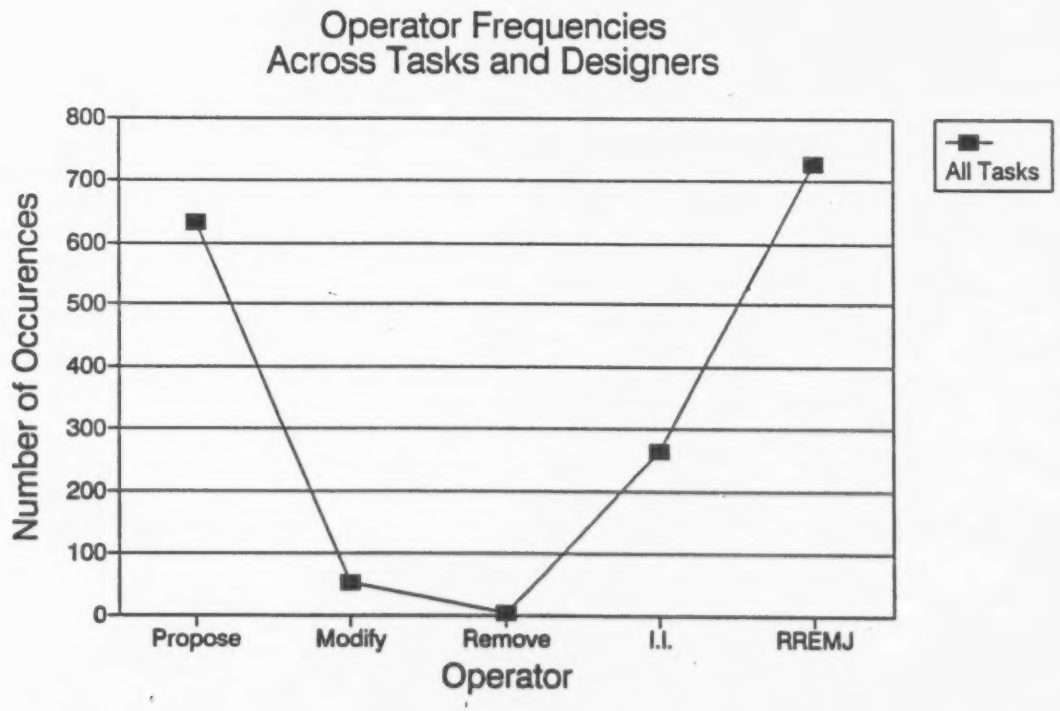


Figure 26a

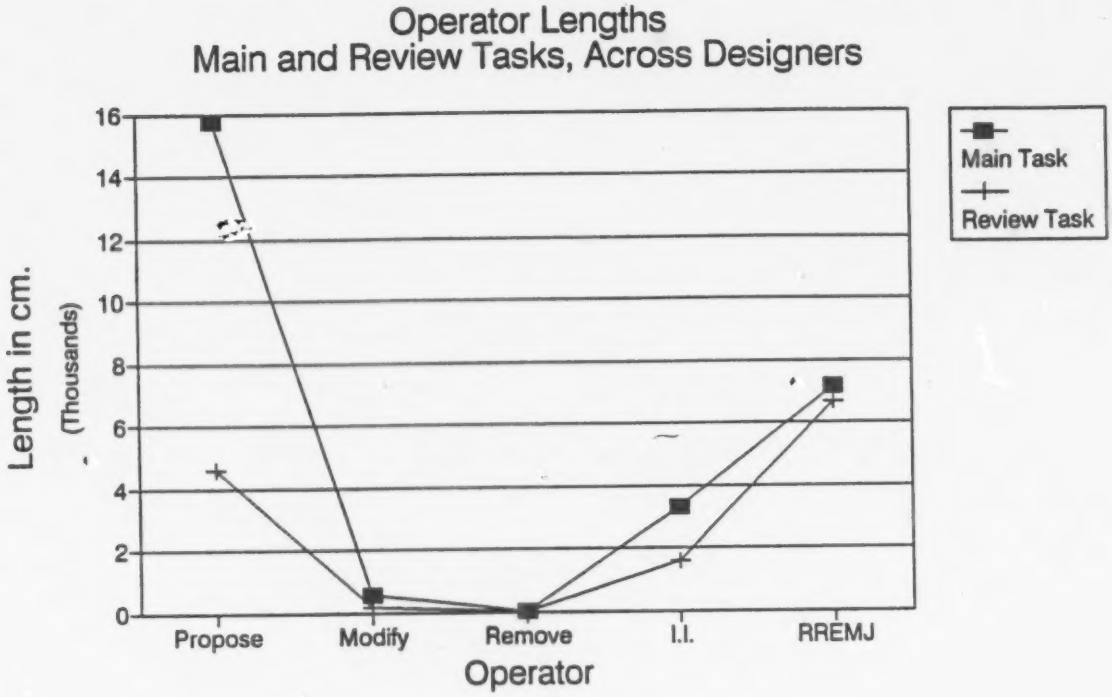


Figure 26b

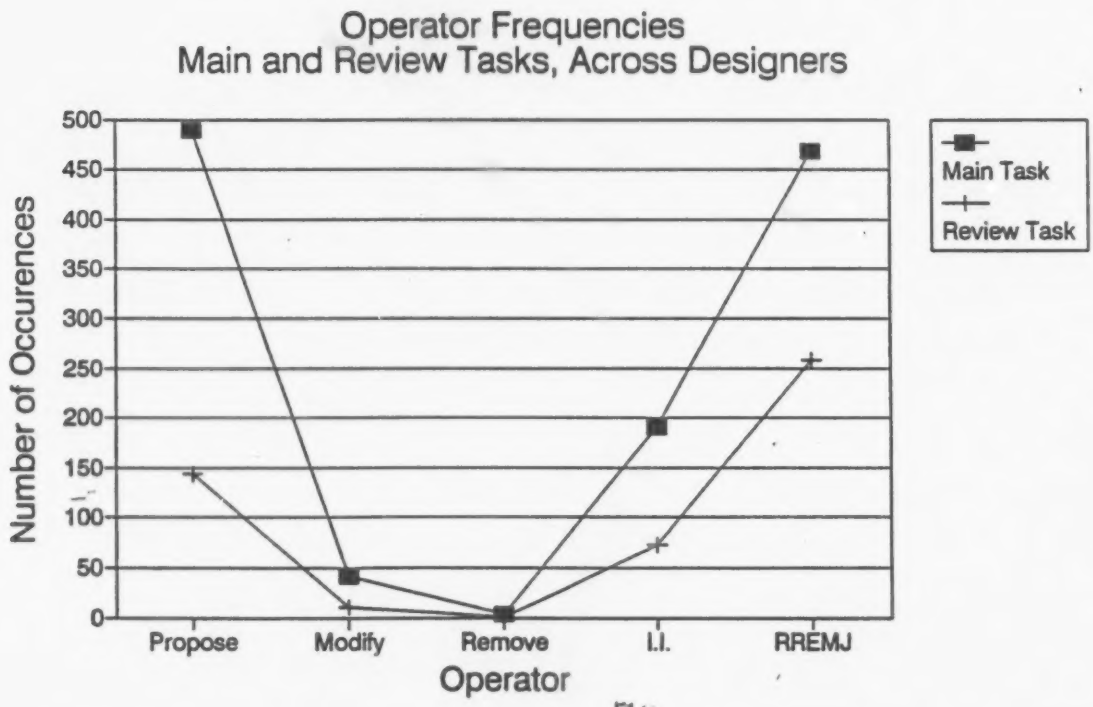


Figure 27a

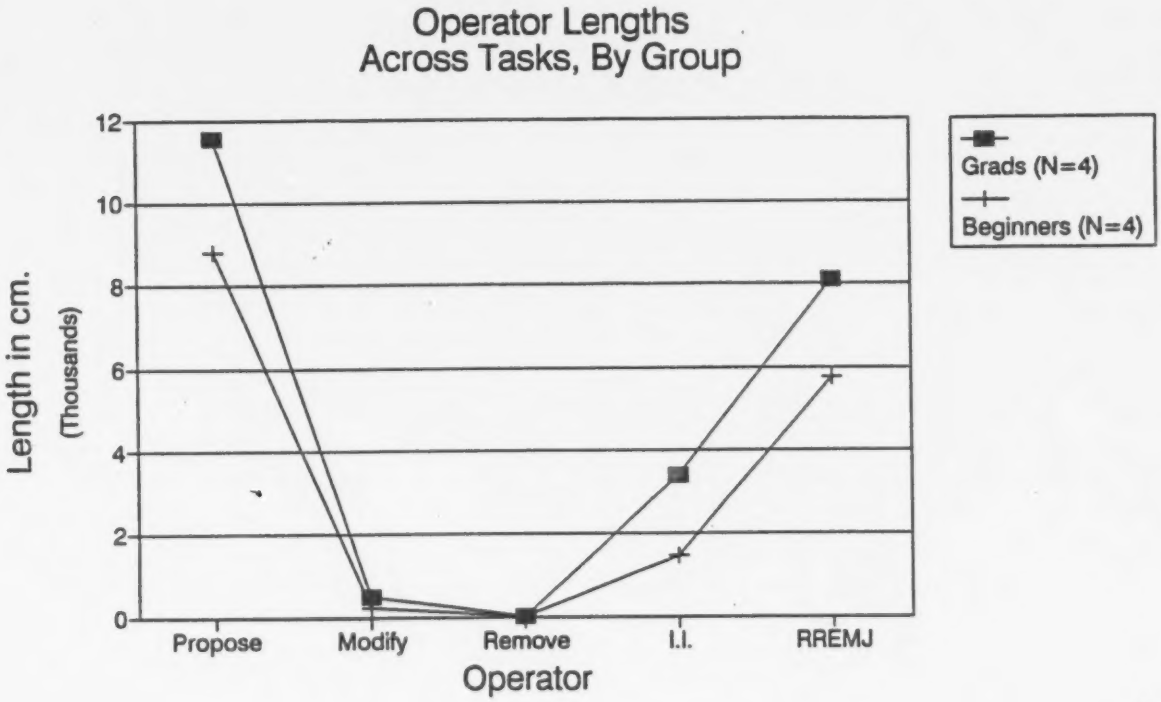
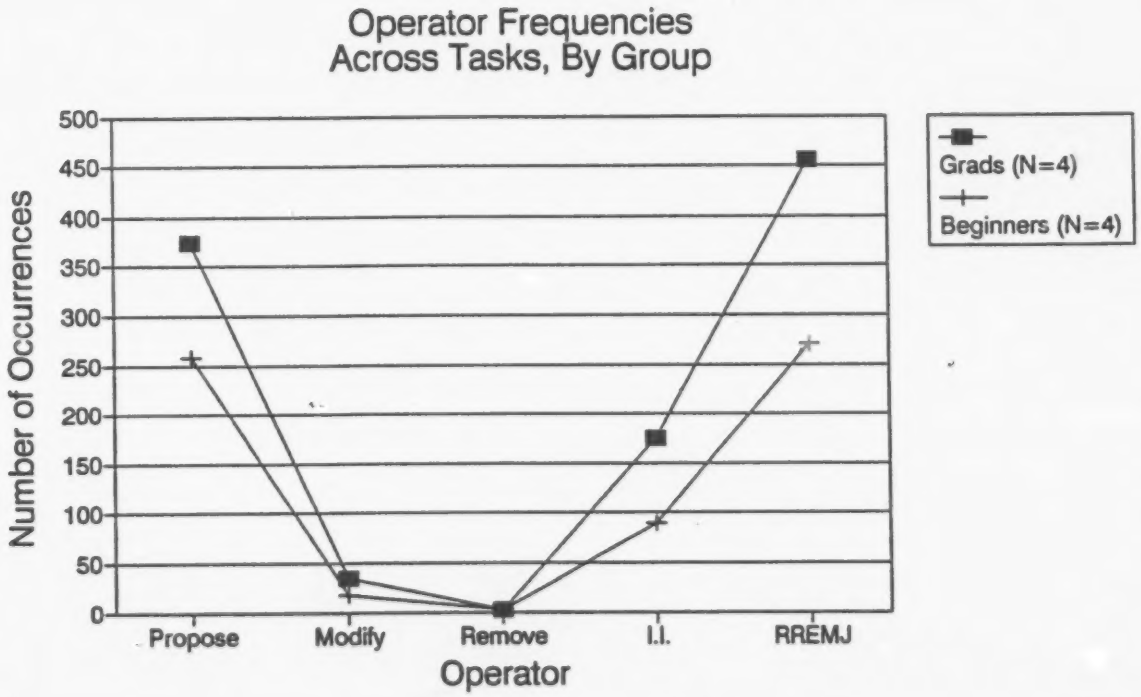


Figure 27b



Whereas the graduate students used RREMJ more frequently than Propose, the new students used both operators in roughly the same frequency. The greater frequency in use of the RREMJ operator across designers is, therefore, accounted for by the graduate students.

First vs. Second Design Task. Figure 28 compares the length of operator segments (summed across designers) in the tasks performed first and second. The graph indicates that the first task is greater in overall length. When the overall length of each design is controlled for, the relative percentages of operator use are the same for the first and second designs.

Comparison of Principles vs. Operations Tasks. Figure 29a compares operator use on the principles and operations tasks. In both tasks the Propose operator is used more than the RREMJ operator. However, propose is used almost twice as much as RREMJ in the principles task, whereas it is used only slightly more in the operations task. In terms of frequency (see Figure 29b) the reverse is true: RREMJ is used only slightly more frequently than Propose in the principles task, whereas in the operations task RREMJ is used relatively more frequently.

Patterns of Work on Operators Over Time. The use of operators in the sequence of episodes is discussed here in relation to the data presented in the graphs found in Appendix VI. The most salient distinctions among the designs in this temporal dimension relate to the order in which the designers use the Propose and the Reflect/Remove/Evaluate/Monitor/Justify (RREMJ) operators. This distinction is particularly noteworthy in relation to whether or not the designers were engaged in the main or review tasks; for most designers Propose was used predominantly or exclusively in the main section, while RREMJ dominated the review section. Also, there is a noticeable difference between designers that intersperse use of these two main operators, and designers that "chunk" operator use; some designers switch back and forth between operators much more frequently than do others.

Protoypical pattern. In the operations task, Designer G1A used operators in what can be described as a prototypical pattern: the primary and almost unique operator used during the main part of the design task is Propose, and the primary

Figure 28

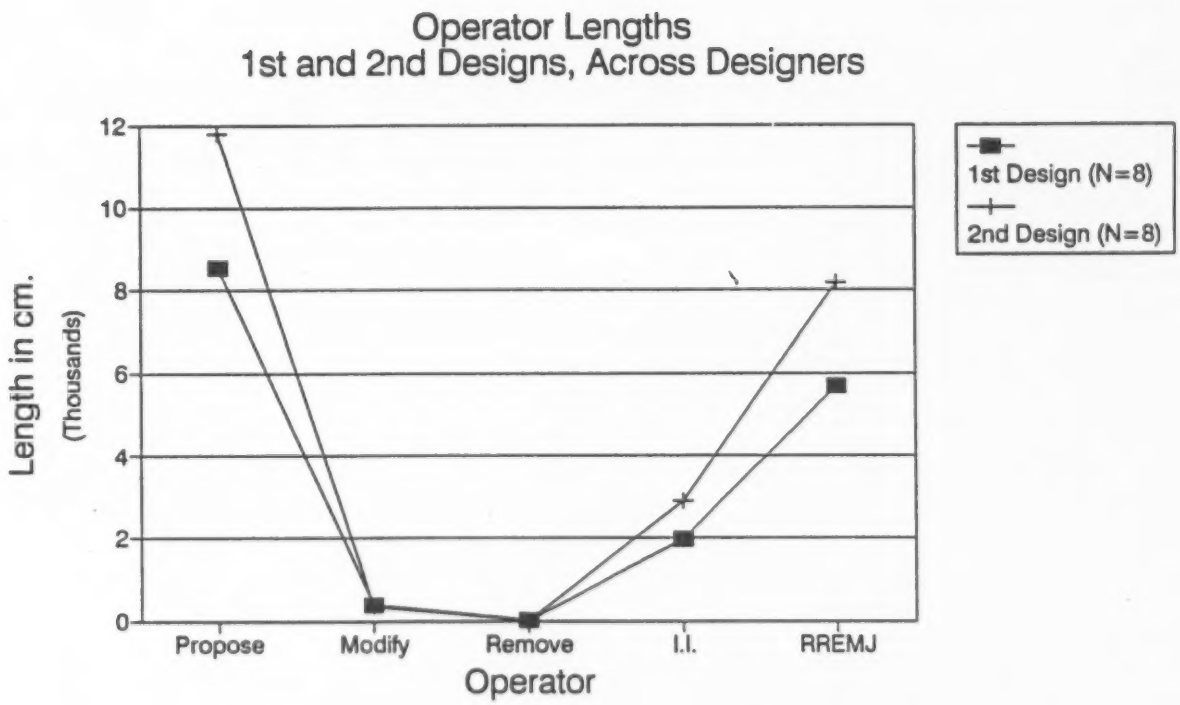

Operator Lengths
1st and 2nd Designs, Across Designers
Length in cm.
(Thousands)
12
10
8
6
4
2
0
Propose
Modify
Remove
I.I.
RREMJ
Operator
1st Design (N=8)
2nd Design (N=8)

Figure 29a

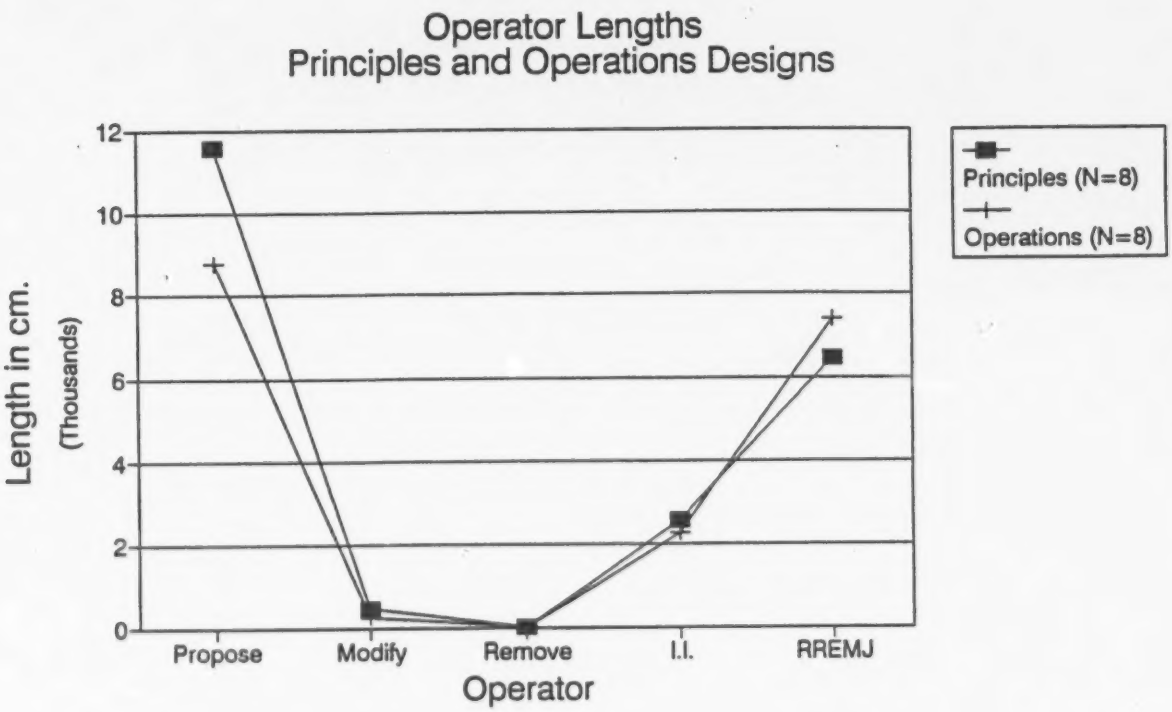
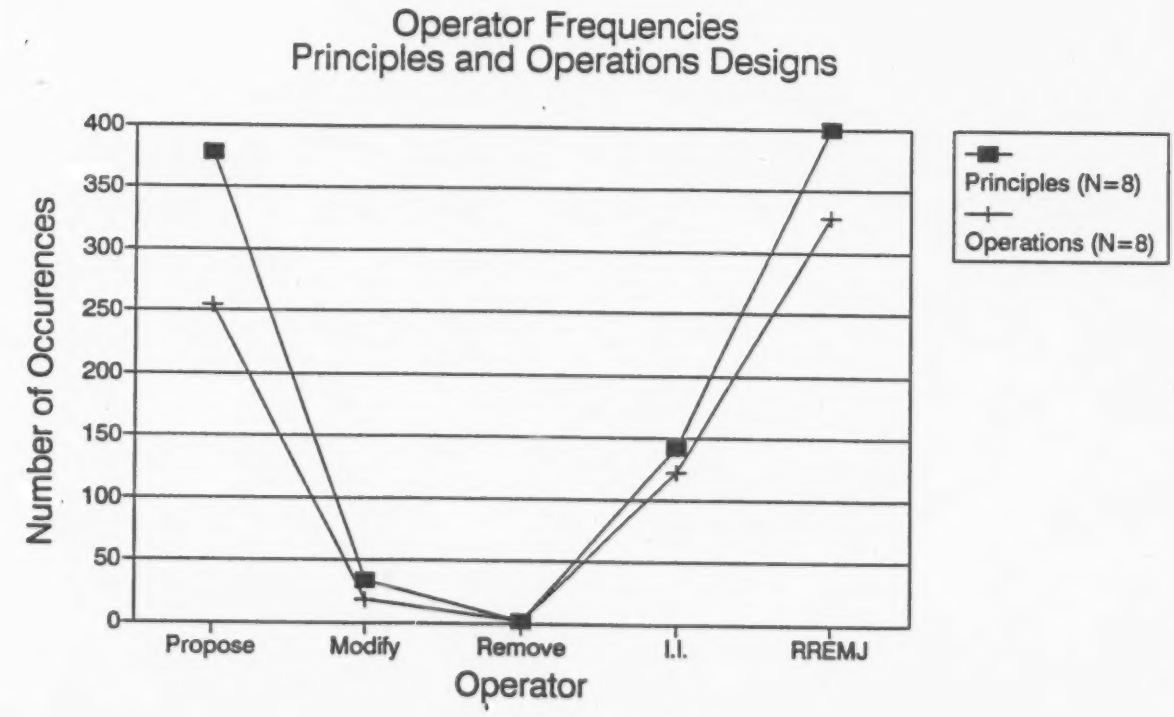


Figure 29b



operator used in the review task is the meta-cognitive RREMJ operator. G1A uses Include Information occasionally, mostly in the main part of the design task. N1B follows a similar pattern in use of the two main operators. In the principles task, Propose is used, with only a smattering of RREMJ (and Include Information), in the main part of the design. The review is almost all RREMJ. The main portion of the operations task, performed second by this designer, is also fairly prototypical, but the latter portion of the review section includes a significant amount of use of the Propose operator.

It is noteworthy that these designs--G1A operations, and N1B operations and principles--all followed the prototypical subproblem pattern, in which Determine Content dominates the main section of the design and use of subproblems in the review section reflects the sequence in which the designers were asked to go over their designs.

Variations on the prototypical pattern. Several designs follow variation of this prototypical pattern. Although Propose is still the primary operation carried out in the main part of principles design created by G3A, the designer frequently diverged from this in short segments to reflect on what had been proposed. Designer G3A also primarily uses the RREMJ operator in the review, but spends most of the latter portion of the review task proposing additions to the design. A very similar pattern is followed in both tasks performed by Designer G4B. Among these three design tasks the primary differences are that G4B used less Propose in the review section of the operations task, and less RREMJ in the main section of the principles task.

The greater complexity in use of operators in these designs mirrors the greater complexity in subproblem use; both these designers tended to work on many subproblems within an episode, and they also tended to reflect often on their design, switching back and forth frequently between operators.

Further variations on the protoypical pattern. Designer N4A exemplifies a different variation on the prototypical pattern. N4A's very short operations design was created with use of exclusively the RREMJ operator in the review section, but the main section, instead of being primarily Propose, is approximately two-thirds Propose and one-third RREMJ. N4A's more lengthy principles design task was created with similar

use of operators, although there is a bit of Propose in the review. Designer N3B in the operations task used operators in a similar but more balanced pattern: an even mix of Propose and RREMJ in the main section, with RREMJ used primarily in the review. To the extent that N4A and N3B used Propose in the review section in these designs, it was towards the end of this section.

Again, as with the other operator patterns, we see a similarity between operator and subproblem use. For N4A and N3B, the use of lengthy proportions of both Propose and RREMJ in the main part of the design mirrors the heavy use of both Determine Content and the Determine Transaction/Resource subproblems in the same section.

Alternative patterns. An alternative operator pattern used by the designers included primary use of Propose throughout both the main and review sections of the design process. To the extent that RREMJ was used in this pattern, Designer N3B regularly interspersed it with Propose in the principles task; Designer G1A, also in the principles task, used RREMJ heavily at the beginning of the review, but followed the same pattern as N3B otherwise. Designer N2A starts both the main and the review sections of the principles task with more RREMJ than Propose, but overall still uses more Propose.

In Designer N2A's particularly brief operations task, the distribution between use of Propose and RREMJ is almost half-and-half, although Propose is more dominant in the beginning of the main portion. (N2A's designs are idiosyncratic in their brevity and also in the fact that the review sections are much longer than the main sections in both tasks.)

Designer G2B followed a similar pattern in the principles task: more Propose in the beginning of the main section, but otherwise a balanced interspersion of Propose and RREMJ. (Propose is, however, more dominant than RREMJ in G2B's principles design, unlike in the operations design of N2A.) G2B's principles design is also, like N2A's designs, significantly longer in the review than in the main section. Overall, however, it is much longer, and therefore this pattern stands out more clearly in G2B's process than in N2A's. It is noteworthy that G2B uses almost as much of the Include Information operator as the RREMJ operator in this task.

The two most idiosyncratic uses of operators occurred in G2B's and G3A's operations tasks. Designer G2B uses primarly

the RREMJ operator throughout both portions of this task, and also uses a great deal of Include Information as well. Propose is used much less frequently than even Include Information. It is used interspersed with these others, although most use of the Propose operator clustered into three equivalently-lengthy groups, two of which were in the main section of the design task. The main section of this design task is shorter than the review; there was, therefore, proportionately more Propose in this section.

The operations task, as performed by G3A, was begun using a solid block of the Propose operator. The designer then shifted for the second half of the main section to a primarily RREMJ operator, broken by the use of one "chunk" of Include Information and two shorter "chunks" of Propose. The review section of the task began with the use of the RREMJ operator; half-way through, the designer switched to proposing, an activity interrupted only briefly for some Reflect/Review/ Monitor/Evalute/Justify.

Relationship Between Subproblem and Operator Use. Among all the designs using alternative operator patterns, there is a pattern in the relationship between operator use and subproblem use. For those designs such as N3B and N2A (Principles design for both), the prototypical subproblem pattern, with its emphasis on Determining Content, occurs in conjunction with heavy use of the Propose operator throughout the design. As the designs deviate from this subproblem pattern, they also show more use of operators other than Propose. For example, G2B (Principles) uses an alternative subproblem pattern comprised of a balance between Determine Content and Determine Transaction as well as a balanced interspersion of the Propose and RREMJ operators. The most idiosyncratic use of subproblems co-occurs with the most idiosyncratic use of operators; G2B and G3A (Operations task for both) used both subproblems and operators in ways unique to that design.

Use of Include Information. The Include Information operator was used almost exclusively in the main part of the design task in 11 of the 16 designs created by the eight designers. Of these eleven designs, five did not use the Include Information operator at all in the review portion of the task. The six other designs used Include Information in both the main and review sections in roughly proportionate amounts across the sections. Of these six designs that used Include

Information in the review portion of the task, four of them were operations as opposed to principles tasks. Three of these four operations task designs were the tasks that were performed first by the designer.

Summary. Overall, the Propose operator is used twice as much as RREMJ, which is, in turn, used three times as much as Include Information. Use of the other two operators--Remove and Modify--is negligible. There is little difference between the various subgroups of our designers in the way they used operators.

Differences in operator use among the designers can be seen most clearly in our analysis of operator use over time. For most of the designs, a shift between use of Propose and use of RREMJ as the primary operator occurs between the main and the review sections of the design. Among these designs there are varying degrees to which the designer used Propose in the main section and RREMJ in the review. Designers who did not make this shift used either mainly Propose throughout the design, or some fairly consistent balance of Propose and RREMJ throughout the design. Exceptions to this were seen in two idiosyncratic designs where there was heavy use of Include Information. One of these designs showed a pattern of operator use in lengthy chunks; the other design showed and intricate interspersion of use of operators. Among all the designers this distinction between using operators in lengthy blocks and interspersing them--usually, switching back and forth frequently between Propose and RREMJ--can be seen.

Differences in patterns of operator use reflect differences in use of subproblems. Generally, heavy use of Propose co-occurs with use of the Determine Content subproblem. Complex patterns of subproblem use are accompanied by more use of RREMJ, and by more frequent switching around among the operators.

Discussion

Problem solving in tasks of design has presented a challenge to the information-processing theory of problem solving because design tasks are relatively weak in their specification. The goal of a design problem is to make something, but the details of what will count as a solution are not specified. The state space of the problem is not specifiable in advance because the problem solver generates the materials that are used in solving the problem. And the operators of the problem are specifiable only in a very general way (e.g., "add material to the problem space").

Some problematic characteristics of design problem solving have been identified in theoretical discussions. Reitman (1965) collected a protocol from a musical composer while he was working on a fugue. Reitman saw that important constraints developed during work on the problem as consequences of the musical material that had been included in the piece and the features of the music that had been composed. This contrasts with well-structured problems in which the constraints are specified -- or at least are specifiable -- in advance.

Simon (1973) examined records of a meeting of a committee for the design of a ship and saw that the problem-solving activity was distributed among different individuals with varying expertise (about sails, hull construction, etc.). Simon concluded that a general feature of ill-structured problem solving is the distribution of activity among multiple problem spaces, including the need to recognize problems while working in one space that can be solved in a different space and to coordinate the results of work in the various spaces.

Recent research has studied solving problems of design and composition in several domains. Kant and her associates have studied the design of an algorithm (Kant, 1985; Kant & Newell, 1983). Stauffer and his associates have studied design problem solving in mechanical engineering (Ullman, et al., 1988). Design of a residential building was studied by Akin (1984). Allen (1988) studied graphics designers working on a poster advertising a musical event. And Getzels and Csikszentmihalyi (1976) studied art students composing drawings. Design of experiments in microbiology was modeled by Stefik (1981). A problem of designing

an administrative-political policy was studied by Voss and his associates (Voss, et al., 1983). Several investigators have studied composition of written essays (Bereiter & Scardamalia, 1987; Hayes & Flower, 1980, etc.).

A Characterization of Design Problem Solving

Our analysis of design problem solving in this report uses a characterization that includes general features of design problem solving that have been found in the studies of various domains. First, we characterize the task of design problem solving in terms of three subproblems: determining the materials to be used in the design, determining the arrangement of the materials, and determining details of implementation. Second, we distinguish different types of knowing that the designer employs. Most of the types of knowing are in two categories: knowing the domain in which the design occurs and knowing the genre of objects that the design belongs to. Third, we distinguish interacting subprocesses: formulating the problem, including generating goals and constraints, adding components to the design, and elaborating and modifying components that have been included in the design.

Subproblems. A designer or composer has to determine what materials will be included in the design or composition, and also what arrangement the materials will have. In many tasks, there are detailed requirements that have to be met, resulting in problems of implementation.

Examples of the materials-arrangement distinction in instructional design involve deciding what content to include in instruction vs. deciding the sequence of topics. In their model of written composition, Bereiter and Scardamalia (1987) distinguished two problem spaces: one involving the content of the essay and the other involving the essay's rhetorical structure. In Allen's (1988) study of poster design, designers thought of images that they wanted to include and worked on how to arrange expressions of the images in the visual space of the poster.

The distinction between general design decisions and implementations occurs whenever design or composition proceeds by progressive refinement. In instructional design, there are general decisions to include topics and locate them in a sequence, and there are more detailed decisions about specific instructional transactions. Allen's (1988) graphics designers worked out details

of their expressions after they had generated sketches. Kant and Newell's (1983) model of algorithm design begins with a kernel schema and proceeds with more detailed instantiations of components. Stefik's (1981) model of experimental design proceeds by top-down refinement as a form of planning. The knowledge given to Warrier's (1989) SOAR-type model of mechanical engineering design is arranged in multiple levels of generality, both regarding the forms and the functional requirements of the device to be designed.

Types of Knowing. A designed object generally has content or performs some function in a domain. It also is an object in its own right, with properties that are characteristic of its genre. The designer's knowledge of the domain and the genre both are important in the process of designing.

In instructional design, this distinction is reflected in the classic dichotomy between experts in a subject-matter domain and experts in instructional design, pedagogy, and learning. Bereiter and Scardamalia's (1987) model of writing essays distinguishes content and rhetorical structure of compositions as different problem spaces. Similarly, Kant and Newell's (1983) model of algorithm identifies knowledge in the application domain (geometry, in this case) and knowledge about algorithms with different problem spaces.

There are important differences in types of knowing within the two general categories of content and genre. For example, in instructional design, knowledge of content includes specific information that is to be presented as well as general knowledge in the domain that is related to the specific topic. Similarly, knowledge about pedagogy and learning includes the designer's knowledge of general principles of teaching and learning as well as knowledge about the teaching and learning of the specific concepts and skills in the lesson. In constructing a design of a machine, knowing in the content domain includes knowing about functions as well as forms of device components (Ullman, et al., 1988).

Subprocesses. The designer reaches an understanding of the design problem, including formulating goals, constraints, and a general approach. Another kind of process puts possible materials into the design, and a third kind of process evaluates materials proposed for the design, elaborates on them, or modifies or removes the materials.

Allen (1988) noted that the processes of design are strongly situated, with the design activity occurring as an interaction of the designer and the environment. The designer places material in the situation, and ideas emerge in the designer's recognizing affordances in the features of the material that has been introduced. Akin (1984) characterized the process of architectural design as having a "constant generation of new task goals and redefinition of task constraints" (Akin, 1984, p. 205).

Several investigators have found that problem solvers who are more experienced or more successful in design and composition engage in a greater amount of problem finding and reformulation than those with less experience or success. Getzels and Csikszentmihalyi (1976) studied many aspects of artistic performance of students at the School of the Art Institute of Chicago, and found that the amount of time they spent in formulating a problem before beginning a drawing, and the amount of time they spent evaluating and reformulating their artistic goals as they worked, were strongly correlated with the judged creativity of their products and with the success they achieved in their careers during the five years after they graduated. Voss et al. (1983) gave students and political science professors the problem of developing a policy for an official to increase agricultural production in a district of the Soviet Union. The main difference between experts and novices was in the greater amount of attention that experts were able to give to considering constraints on the problem

Relations to Other Kinds of Problems

Design and composition problems share significant features with arrangement problems, such as anagrams and cryptarithmetic. Design and composition problems require an arrangement of components that satisfies a set of constraints. The major difference is that in arrangement problems the materials are given, while in design and composition, materials have to be generated by the problem solver.

The subprocesses of generating materials and evaluating, elaborating, and modifying the materials are analogous to the subprocesses of inductive problem solving: generating hypotheses and obtaining data to evaluate, elaborate, and modify the hypotheses. These subprocesses have been identified with different problem spaces in some analyses of inductive problem solving (Simon & Lea,

1974; Klahr & Dunbar, 1988). The interactive nature of design subprocesses, emphasized by Allen (1988), makes it seem inappropriate to define separate problem spaces for them in design and composition problems. There may be situations involving induction in which problem solving is similarly situated, especially when the scientific endeavor includes the design of theories, rather than construction of hypotheses within a fixed conceptual framework.

Insight problems, studied by gestalt psychologists, seem to be good examples of design problems as we characterize them here. There are numerous materials available, and the problem-solver's task is to find a set of the materials and a way to arrange them to satisfy the problem constraints. The situated perspective on design problem solving might prove quite useful in understanding the solution of insight problems, especially as a process of discovering affordances.

Finally, the present analysis, and nearly all the available research, considers design as a process conducted by an individual. This seems an unfortunate limitation, and it would be desirable to study processes of design by groups,.

Acknowledgements

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References

Akin, O. (1984). An Exploration of the Design Process. Developments in Design Methodology, 189-207. John Wiley and Sons.

Allen, C. (1988). Situated Designing. Unpublished Masters Thesis, Carnegie-Mellon University, Pittsburgh, Penn.

Bereiter, C. & Scardamalia, M. (1987). The psychology of written composition. Hillsdale, NJ: Lawrence Earlbaum Associates.

Ericsson, K. A. & Simon, H. A. (1984). Protocol Analysis: Verbal Reports as Data. Cambridge, Mass: The MIT Press.

Getzels, J. W. & Csikszentmihalyi, M. (1976). The Creative Vision. New York, NY: Wiley.

Goel, V. & Pirolli, P. (1989). Motivating the notion of generic design within information processing theory: The design problem space. Unpublished manuscript, University of California, Berkeley, CA.

Greeno, J. G. & Berger, D. (1987). A model of functional knowledge and insight (Tech. Rep. No. GK-1). Berkeley, CA: University of California, School of Education.

Greeno, J. G. & Berger, D. (1990). Knowledge about system components and functions in diagnostic problem solving (Tech. Report). Stanford, CA: Stanford University, School of Education.

Greeno, J. G., Korpi, M. K., Jackson, D. N. & Michalchik, V. S. (1990). Processes and knowledge in designing instruction (Tech. Report). Stanford, CA: Stanford University, School of Education.

Greeno, J. G., Magone, M. E., & Chaiklin, S. (1979). Theory of constructions and set in problem solving. Memory and Cognition, 7, 445-461.

Greeno, J. G. & Simon, H. A. (1988). Problem solving and reasoning. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), Steven's handbook of experimental psychology: Vol. 2: Learning and cognition (2nd ed.) (pp. 589-672). New York: Wiley & Sons.

Guindon, R. (1988). Software design tasks as ill-structured problems, software design as an opportunistic process (Report No. STP-214-88). Austin, TX: Microelectronics and Computer Technology Corporation.

Hayes, J. B. & Flower, L.S. (1980). Identifying the organization of writing processes. In L. W. Gregg & E. R. Steinberg (Eds.), Cognitive processes in writing. Hillsdale, NJ: Erlbaum.

Kant, E. (1985). Understanding and automating algorithm design. Proceedings of the Ninth International Joint Conferences on Artificial Intelligence (Vol. 2, pp. 1243-1253).

Kant, E. & Newell, A. (1983). An automatic algorithm designer: An initial implementation. (Proceedings of AAAI-83, pp.177-181).

Klahr, D. & Dunbar, K. (1988). Dual space search during scientific reasoning. Cognitive Science, 12, 1-48.

Korpi, M. (1988). Making conceptual connections: An investigation of cognitive strategies and heuristics for inductive categorization with natural concepts. PhD Dissertation, Stanford University, Stanford, Ca.

Newell, A. & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Reitman, W. R. (1965). Cognition and thought: An information-processing approach. New York: Wiley.

Simon, H. A. (1973). The structure of ill-structured problems. Artificial Intelligence, 4, 181-201.

Simon, H. A. & Lea, G. (1974). Problem solving and rule induction: A unified view. In L. W. Gregg (Ed.), Knowledge and Cognition. Potmac, MD: Erlbaum.

Stefik, M. (1981). Planning with constraints (MOLGEN: Part 1). Artificial Intelligence, 16, 111-140.

Steier, D. S. & Newell, A. (1988). Integrating multiple sources into Designer-Soar, an automatic algorithm designer. Proceedings of the AAAI-88 Seventh National Conference on Artificial Intelligence (Vol. 1, pp. 8-13).

Ullman, D. G., Dietterich, T. G. & Stauffer, L. A. (1988). A model of the mechanical design process based on empirical data. Manuscript submitted for publication.

Voss, J. F., Greene, T. R., & Penner, B. C. (1983). Problem solving skill in the social sciences. In G. H. Bower (Ed.), The psychology of learning and motivation: Advances in research theory (Vol. 17, pp. 165-213). New York: Academic Press.

Warrier, U. S. (1988). A SOAR-based computational model of mechanical design. Research paper submitted to Oregon State University, Corvallis, Oregon.

Appendix I: **VST2000 Tutorial Screens**

Appendix I: VST2000 Tutorial Screens

$1
Introduction
As a new Earth vehicle, the VST 2000 attempts to meet the world's need for more energy efficient transportation. Although this new product looks very similar to standard vehicles, it uses an advanced energy system. The VST 2000 can run in a variety of ways on energy derived from both internal and external sources. Sources of stored energy include the sun, raw energy tablets, and chemical energy stored in vegetable matter. However, before the vehicle functions, raw energy must be extracted from these diverse sources, converted to a common form, and then filtered to meet the requirements of the motor. A system of wires and switches transport the energy from the source to the motor.

$2
In this tutorial you will learn about the processes that take place inside the VST 2000 energy system:
1. Extracting raw energy stored and used in the VST 2000.
2. Converting raw energy to other forms of energy.
3. Purifying impulse energy.
4. Transporting energy from the source to the motor.

$3
These processes illustrate several general scientific concepts and principles:
a) Energy storage and extraction
b) Forms of energy
c) Transportation and switching of energy within a system
d) Conversion of energy from one form to another
e) The use of local electricity to power system units.

$4
In this section, we provide a rationale for the VST 2000. First, we introduce the three units that make up the VST 2000 energy system. Next we describe how units are connected together so that energy can be transported from one unit to another. After completing this instructional segment, you will be able to:

1. Provide a rationale for building the VST 2000.
2. Describe the VST 2000's 5 units
3. Describe how the units can be connected.

$5
The VST2000 has two innovative features. First, it can use energy from one of two independent sources to run the vehicle while simultaneously storing energy in a third source. Second, an owner can easily rearrange the flow of energy to and from the units of the VST2000 to take advantage of different operating conditions.

$6
QUESTION
One feature of the VST2000 system is
a: its unique appearance compared to standard vehicles.
b: its single-arrangement energy system.
c: its ability to use and store energy simultaneously

$7
The three different units of the VST 2000 are: (1) the Tablograph, (2) the Vegetor, (3) the Impulse Purifier. In addition, the VST 2000 has a Motor and a bank of 5 Switches. Look at the Display Window to the right of this text and locate the units, motor indicator and switches now. Notice that each unit has several constituent parts. You will be introduced to all of constituents shortly. Find the 2 types of switches, the 3 I-type and the 2 O-type. Most of the VST 2000 Motor is not included in the diagram. Only the box labeled "Indicator" is visible to tell you whether the motor is receiving energy, and, if so, from which unit.

$8
There are 4 forms of energy that the VST 2000 uses: raw, impulse, purified, and mechanical. The three energy source units (the Tablograph, the Vegetor, and the Impulse Purifier) must have their local electricity turned on to work.

$9
The "lines" on the screen represent wires that interconnect constituents and units. Light wires on the screen carry local electricity. Heavy wires carry any of the 4 forms of energy (but not local electricity). Locate several light and heavy wires on the diagram now. Try to start at each of the three energy sources and follow the possible paths of energy through the system to the motor.

$10
In the VST 2000 system,
a: the three energy source units do not need electricity to work.
b: local electricity and all forms of energy flow through the same wires.
c: electricity does not flow through the switch bank unit.

$11
Energy Sources:14B - 30B
All vehicles use some form of stored energy to operate. Conventional automobiles, for example, rely on the energy stored in gasoline. Similarly, old fashioned steam railroad engines burn coal to convert its energy into heat which boils water to form steam that pushes pistons connected to the wheels.
The VST 2000, like these vehicles, uses energy stored in a variety of forms--solar (in the Sun), nuclear (in the tablet of the Tablograph) and chemical (in the energy bar of the Vegetor).

$12
To run, vehicles must have a way to extract their stored energy, then convert it into forms usable for locomotion. These extraction and conversion process themselves require electricity to run the constituents parts. Consequently, many vehicles have batteries or other local electricity sources. Automobile engines, for example, extract energy stored in gasoline to turn the wheels. But local electricity, from the battery and/or the alternator, is needed to produce the spark that ignites the fuel. Once ignition has begun, its energy is converted to the mechanical energy required for locomotion and transported to the wheels.

$13
Similarly, the VST 2000 relies on local electricity to run the constituents that convert stored energy to usable power. The processes which generate electricity in the VST 2000 are beyond the scope of this lesson so you may simply assume that electricity is always present at each power plug. As in the automobile, energy conversion is a multi-step process. First, energy source units extract the energy from its source as raw energy. Next, converters convert the raw energy into the impulse form. After flowing through the switch bank the impulse energy enters the Impulse Purifier where it is again converted, this time into purified energy. Purified energy leaves the energy system and enters the motor at the indicator. Thereafter it becomes mechanical energy for locomotion.

$14
This section describes the extraction process and discusses the three energy extracting units in more detail. We also explain the procedures for operating each unit. First, we identify energy storage constituents associated with each source unit. Then, for each source, we describe the local electrical constituents that must be manipulated to produce energy. Finally, we give you concise operating instructions. After completing this section you will be able to:

1. Identify the three units that store and extract energy.
2. Describe their respective stored energy sources.
3. Describe the role of state switches for running each unit.
4. Use local electricity to extract raw energy.

$15
The three units in the VST2000 system are: the Impulse Purifier, the Tablograph and the Vegetor. Each of these source units gets its energy from a different storage medium.

$16
The Photo-Receptor/Solar Pack is the constituent within the Impulse Purifier that gets energy from the Sun's rays; the Tablograph gets its energy from the Tablet; and the Vegetor's energy comes from the rechargeable vegetable particles of an Energy Bar.

$17
QUESTION
The Tablograph, the Vegetor and the Solar Pack
a: are the 3 units of the VST 2000 system which consume energy.
b: extract raw energy from a Tablet, an Energy Bar and the sun's rays, respectively.
c: extract purified energy using different processes but the same source of stored energy.

$18
Solar energy is only available when the sun is shining. To make the sun shine on the Photo-Receptor, press in the "Sunshine" button. Once the sunshine is turned on it stays on until you turn off the computer simulation.

$19
The Vegetor gets its raw energy form an Energy Bar. The bar is made of vegetable matter that can be scanned for its chemical energy. Vegetable matter can only be scanned once after which it must be recharged.

$20
The Tablet is made up of an infinite number of particles that give off raw energy continuously so no special steps are needed to operate the Tablograph.

$21
QUESTION
The Vegetor's Energy Bar
a: can only be scanned once after which it must be recharged.
b: is made up of an infinite number of particles that are constantly giving off raw energy.
c: can be scanned many times before being recharged.

$22
The three VST 2000 units have several similar constituents, an energy extraction device, a converter, a state switch, and connecting wires. Each State Switch controls the flow of electricity from its local power plug to the rest of the unit. When the switch is in the "on" position the unit will operate. Conversely, no constituent of the component will operate when the switch is "off."

$23
The Tablograph's State Switch has 2 positions, "H" for halt and "P" for produce which correspond "off" and "on." Find this switch on the diagram and use the mouse to turn it on and off. Slide the mouse on the table so that the arrow is over the desired switch position, then push the ??left?? button. It may take several seconds for the computer simulation that controls the diagram to redraw the switch. It takes practice to position the arrow properly so try again if the switch does not respond.

$24
Similarly, the Impulse Purifier has a State Switch with 2 positions: "+" for on and "-" for off. Note that the solar pack and its converter as well as the purifier are all constituents of the Impulse Purifier unit. Because energy which originates in either the Tablograph or the Vegetor must pass through the working Purifier, the Impulse Purifier's electricity should be on whenever the VST 2000 is in use. Find the Impulse Purifier's State Switch and turn it on.

$25
The Vegetor has a three position State Switch with position, "R," for Recharge as well as P (on) and H (off). Find the Vegetor state switch and try each State Switch position using the mouse. Note the path of the light (electrical) and the heavy (energy) wires. We will discuss the use of the Recharge position shortly.

$26
QUESTION
Unit State Switches
a: may be the 2 position or 3 position variety.
b: can have only 2 possible states.
c: turn individual constituents off and on within a unit.

$27
In the VST 2000, state switches control the flow of local electricity to the Vegetor, the Tablograph, and the Impulse Purifier. Once energized, these units can extract, convert, and pass on the energy needed to move the VST 2000.

$28
In this segment, we will describe the constituents of each unit and the procedures used to operate them. Additionally, we will discuss energy extraction. After completing this section, you will be able to:
1. Describe the role of the solar pack's photo receptors.
2. Extract energy from sunshine using the photo receptors.
3. Describe the role of the Tablograph's absorption needle.
4. Extract energy from the Tablet using the absorption needle.
5. Describe the role of the Vegetor's scanner.
6. Extract energy from the Energy Bar using the scanner.

$29
As previously mentioned, each unit extracts raw energy from a different storage source. Once again, these sources are the sun's rays, the Energy Tablet and the Energy Bar. Each unit has a constituent for capturing energy.

$30
There are 3 "extracting" constituents in the system. (1) The Impulse Purifier's Photo-Receptor brings the sun's rays to the Solar Pack. (2) The Tablograph's Absorption Needle picks up energy from the Tablet. And (3) the Vegetor's Scanner derives raw energy from the vegetable matter of the Energy Bar.

$31
DIAGRAM: Needle
Tablet energy is extracted by the Tablograph's Absorption Needle whenever the Tablograph's State Switch is in the P (on) position. Raw Energy from the needle flows to the converter.

$32
QUESTION
The Absorption Needle extracts raw energy from the tablet
a: continuously.
b: only when the Tablograph state switch is in the H position.
c: when both the needle and the converter are receiving electricity.

$33
DIAGRAM: Scanner
Similarly, the charged particles of the Vegetor's Energy Bar are extracted by the Scanner. When the Vegetor's state switch is in the Produce (P) state, the Scanner receives electricity and moves along its track from left to right. If the Energy Bar is charged, then raw energy will flow through the scanner head to the converter. Scan the energy bar now by switching the Vegetor to P with the mouse. (If the Scanner head is already at the right end of the Scanner, go on to the next screen.)

$34
DIAGRAM: Scanner
Once the Scanner has extracted the energy from the energy bar, the scanner must be returned to the left end of the bar and the bar must be recharged. Find the Setup Button on the Vegetor (capital S inside a circle) and use the mouse to activate it (put the arrow over the S and click). When you have done this correctly the scanner will return to the left. Remember that the Vegetor state switch must be on (P or R) for the Scanner head to move.

$39
After energy is extracted as raw energy, it must be converted into a single form usable by the Purifier. This process is similar to the voltage transformation necessary for some household appliances. For example, if you take your American electric shaver (110 volts) to Europe where the wall sockets supply 220 volts, you must use an electrical transformer between them.

$40
In the VST 2000, Converters have been installed within each unit to take in the raw energy and put out impulse energy. In this section, we locate the Converters associated with each unit and highlight their need for electricity to operate. Find the three boxes labeled "Converter" on the VST 2000 diagram. Trace the path of the raw energy from each Extraction device (Needle, Scanner, and Photo Receptor/Solar Pack) to the Converter within each Source unit.

$41
Next trace the path of the impulse energy out of the converters to the TaO and PrO connector plugs. The connector plugs have one heavy wire going in and three heavy wires going out to the three I-type switches. These extra wires permit the VST 2000 operator to transport energy via several different pathways by using different switch combinations.

$42
Trace the possible paths of impulse energy out of the Tablograph and Vegetor converters into their respective switches. The action of these switches will be discussed shortly. Notice that the Solar Pack within the Impulse Purifier does not use the I-type switches and has only one path through the Selector Switch to the Purifier constituent.

$43
Next trace the path of the electricity for each unit from its Power Plug, through the state switch to the converter. Converters only work when their state switches are "on" (P for the Tablograph, + for the Impulse Purifier, and P or R for the Vegetor).

$35
DIAGRAM: Scanner
When the Vegetor state switch is in the Recharge (R) position, raw energy flows in the opposite direction (from the converter TO the scanner), recharging the Energy Bar. In this case, the Scanner will move along the track, left to right, and its head will recharge the Energy Bar's vegetable matter. Thus the Vegetor state switch has two functions: it turns the electricity off (H) and on (P and R) and it directs the flow of raw energy either to (P) or from (R) the converter.

$36
DIAGRAM: Solar Pack
The third "extracting" device is a constituent of the Impulse Purifier unit. Find the Photo-Receptor/Solar Pack and the circle labeled "Sunshine" on the diagram. When sunlight hits the Photo-Receptor, it is focused on the Solar Pack and is passed as raw energy to its converter. In this simulation, the sun can be turned on by clicking on it with the mouse. Once on, the sun stays on. Try manipulating the sun now. Realize that no raw energy can be extracted when the sun is not shining.

$37
QUESTION
DIAGRAM: Scanner
The Vegetor's Scanner head
a: will recharge the Energy Bar by moving from right to left.
b: will recharge the energy bar when the state switch is in the Produce P position.
c: will reset to the left of the Energy Bar when the Setup Button (S) is "clicked" and the State Switch is in the P or R position.

$38
QUESTION
The Photo Receptor/Solar Pack
a: is recharged by raw energy flowing to it from the converter.
b: is a switch constituent in the Vegetor.
c: extracts raw energy only when the sun is shining.

$44
QUESTION
Each source unit's converter
a: converts raw energy into impulse energy.
b: converts raw energy into electricity.
c: operates independently of its unit's state switch.

$45
When the constituents of the Tablograph are viewed as a single unit, the unit has two states, Halt and Produce. These states are set with the State Selector Switch. In the Produce (P) state, the Absorption Needle receives electricity through the State Switch and extracts energy from the Tablet. The Converter receives electricity via the same State Switch and converts the incoming raw energy to outgoing impulse energy. In the Halt State, no energy flows within or out of the Tablograph.

#46
DIAGRAM: V.Converter
Like the Tablograph's Converter, the Vegetor's Converter is activated when its State Switch is on. However, the Vegetor has two "on" positions, P and R. In P, raw energy flows out of the scanner into the Converter. Then Impulse energy flows out of the converter, through the three wire connection labeled "PrO" and on to the I-type Switches. In R (recharge), energy flows in the opposite direction. Purified energy leaves one of the O-type switches, flows through the connection labeled "ReI" and into the Converter. The Converter then puts out raw energy which flows to the Scanner to recharge the Energy Bar.

$47
When the Vegetor State Switch is "off", that is, in the H position, none of the constituents function no local electricity is supplied to the constituents and no energy flows through them.

$48
QUESTION
The Vegetor is different from the Tablograph because
a: the Vegetor's converter can take in raw energy and put out impulse energy.
b: the Vegetor can recharge its source of raw energy (i.e. the Energy Bar).
c: the Vegetor's extracting constituent and its Converter are activated by the same State Switch.

$49
DIAGRAM: SP.Converter
Like the first two units, the Impulse Purifier has an Energy Converter and a State Switch. When the switch is in the on (+) position, the Converter will take raw energy received from the Solar Pack and convert it into Impulse energy. This Impulse energy does not flow into the I-type switches. Instead it flows directly to the Selector Switch within the Impulse Purifier. Find the Converter and the Selector Switch in this unit on the diagram and trace the heavy energy wire between them.

$50
DIAGRAM: SP.Converter
If the Converter does not receive local electricity from the State Switch it will not convert or pass on any energy. Locate the Impulse Purifier State Switch and the path of local electricity along the light wire to both the Converter and the Purifier.

$51
Moving Energy: 60B - 74B
In most vehicles, energy is extracted at one location, converted in another, and used someplace else. Consequently, both energy and electricity must have transportation pathways throughout the system. Typically pipes are used to carry water or gas, optical fibers carry light, and copper or aluminum wires carry electricity. At branching points, the direction of flow is controlled by some sort of switch or valve.
The VST 2000 uses two types of wires, represented in the diagram as light and heavy, to transport electricity and energy. A variety of plugs and switches control the direction of flow.
$51
On the diagram, wires shown as crossing go by each other without connecting. Find the three places where heavy wires cross just above the I-type switches and another place where they cross just below the MO switch. These lines represent separate wires. Lines which touch in a T junction but do not cross DO represent connecting wires. Find the T junctions in the light electric wires between each State Switch and its Converter. There are two additional T junctions in the heavy energy wires, one just above the Purifier which transports energy to both the O-type switches and one in the wire which transports energy from the O-type switches to the Motor.

VST 2000 Tutorial: Revised Screens

$52
In this section, we describe energy transportation in the VST 2000. After completing this material, you will be able to:

1. Describe the flow of energy around the VST 2000.
2. Operate all of the switches to achieve the desired flow patterns.

$53
Energy from the Tablograph and the Vegetor must pass through the I-type switches before entering the Impulse Purifier. Since the Photo Receptor/Solar Pack is internal to the Impulse Purifier, its energy flows directly to the Selector Switch.

$54
Turn your attention to the I- and O-type switches at the center of the VST 2000 diagram. Notice that there are 5 switches each with an upper, middle, and lower position. Practice changing switch positions with the mouse by placing the arrow over the desired position for a switch and clicking the button. Note that the middle position is OFF for all 5 switches. When a switch is OFF, no energy flows through it.

The complex design of these switches allows maximum flexibility to the operator of the VST 2000 but also requires close attention to detail while you are learning about it. Your objective is to create a connected pathway to transport energy from the source medium to the VST 2000 Motor Indicator Box at the right of the diagram.

$55
Look carefully at the I-type switches labeled "TI", "VI", and "AI". There is one wire from the bottom of each switch which is always connected to the Selector Switch in the Impulse Purifier. The position of the I-type switch controls the flow into the switch. The outflow from each switch is fixed.

$56
DIAGRAM: TI.Switch
The TI, VI and AI switches can each receive Impulse Energy from the Tablograph by setting the switch in the up or TaO position. Likewise, when each of these switches is set in the down position or PrO position, energy can flow from the Vegetor.
When the switch is in the OFF position, no energy will flow through it.

$57
QUESTION
The TI, VI and AI switches
a: correspond to the Purifier's output plugs.
b: can receive energy from either the Tablograph or the Vegetor.
c: will allow energy to flow when set at any position.

$58
To protect the Motor from damage, Impulse Energy must be purified. This process takes place in the Purifier constituent on the Impulse Purifier. The Purifier must have local electricity to operate. In this section, we describe the Impulse Purifier and its operation. After completing this material, you will be able to:
1. Describe the Impulse Purifier.
2. Activate the Impulse Purifier using local electricity.

$59
Energy from either the Tablograph or the Vegetor must flow through the Impulse Purifier to get to the Motor. The Impulse Purifier is a complex unit with several functions. It transports impulse energy via its Selector Switch. It extracts energy from sunshine by means of its Photo Receptor/Solar Pack. It converts raw energy from the Solar Pack into impulse energy in its converter. Finally, it purifies all impulse energy to purified energy using its Purifier.

$60
The Selector Switch on the Impulse Purifier completes the energy pathway from the energy source to the Purifier. The Selector Switch has 4 positions: "S" for Solar Pack, "T" for the TI switch, "V" for the VI switch and "A" for AI switch.

$61
Because the Solar Pack is connected internally to the Impulse Purifier, when the Selector Switch is in the "S" position, it always selects the signal from the Solar Pack. On the other hand, do not assume that energy from the V Selector Switch position comes from the Vegetor. It could be from the Tablograph through the VI switch!

$62
QUESTION
Energy from the Tablograph will be transported to the Purifier when the Tablograph State Switch is on P, the Impulse Purifier State Switch is on + , AND
a: the AI switch is set on Pro and the Selector Switch setting is "S"
b: the TI switch is set on TaO and the Selector Switch is on T.
c: the TI switch is set anywhere and the Selector Switch is on T.

$63
DIAGRAM: Purifier
Like a converter, the purifier is only activated when it receives local electricity from its State Switch. When activated, the purifier will convert the Impulse Energy received from the Selector Switch to Purified energy and pass it to the O-type switches. Find the heavy lines on the diagram which transport purified energy to O-type switches. Note that energy flows to both switches simultaneously through a T junction above the Purifier. Also note that the path from the Purifier into the MO switch crosses but does not intersect with the path from the VO switch to the Motor.

$64
The two O-type switches can direct energy to the Motor and to the Vegetor to recharge it. Both switches have two "on" positions and one "off". When an O-type switch is in the middle (off) position no energy flows through it.

$65
To transport purified energy to the Motor, either the VO switch or the MO switch must be in the down position, labeled "MoI". In order to protect the Motor from receiving too much energy, a safety feature keeps both switches from being in the down position at the same time. Use the mouse to move both O-type switches to the "MoI" position now. Notice that one of the switches returns to "off" after a few moments.

$66
To recharge the Vegetor, an energy path must be created from the Purifier, through one of the O-type switches to the Converter in the Vegetor. Either switch may be set to the "ReI" position to create this path. Note that the heavy wires out of both O-type switches join in a T junction above the switches.

$67
There are seven possible combinations of the two O-type switches: 1) both "off"; 2) the VO switch "off and the MO switch on "ReI" to recharge the Vegetor; 3) the VO switch "off" and the MO switch on "MoI" to run the Motor; 4) the VO switch on "ReI" to recharge the Vegetor and the MO switch on "MoI" to supply energy to the Motor; 5) the VO switch on "MoI" supplying the Motor and the MO switch on "ReI" recharging the Vegetor. Settings 6) and 7) have the MO switch "off" and the VO switch on "ReI" or "MoI".

$68
Try each O-type switch combination on the diagram and trace the flow of energy from the Purifier to its destination in each case. Notice that the Vegetor can be charging and the Motor supplied with energy simultaneously.

$69
To move, most vehicles use stored forms of energy to produce mechanical energy. For example, the energy from ignited gasoline is converted to mechanical energy through the action of pistons. Although the VST simulation does not show motion, one can infer motion through the arrival of energy in the motor indicator. In this section, we describe the motor indicator and how to set the switches throughout the VST 2000 to direct the flow of energy to it. Consequently, when you complete this segment, you will be able to:

1. Interpret the arrival of usable energy in the VST's motor indicator.
2. Send energy to the Vegetor for recharging purposes.

$70
The VST Motor Indicator shows a V, S, or T in the Indicator box depending on the source of energy being received by the Motor. Spend a few minutes working with the simulation to get each letter to be displayed in the Motor Indicator Box. Notice that there are several combinations of I-type, O-type, and Selector Switch settings for each indicated V, S, and T.

$71
QUESTION
The Motor indicator
a: shows the source of the energy being stored in the Vegetor's Energy Bar.
b: shows the source unit of the energy reaching the Motor.
c: reflects the state of the Impulse Purifier.

$72
Here are some questions to ask yourself if you have trouble getting the desired letter in the Motor Indicator Box.

Is the State Switch for the Unit supplying the energy "on"?

Is there a complete path from the Unit, through the I-type and/or Selector Switch to the Purifier?

Does the Purifier have local electricity?

Is there a complete path from the Purifier to the Motor?

Is the Vegetor, if needed, recharged and reset?

Is the sun shinning, if needed?

$73
This is the end of your training on the VST 2000.
Please complete the four Tasks which will be
displayed next on the screen. If you find the tasks
difficult you are welcome to run through the this
instructional sequence again.
Good Luck!

Appendix II: **Think-Aloud Instructions**

Appendix II: Think-Aloud Instructions

Read instructions in boldface:

Today, I'm going to ask you to solve a problem using the information that you learned yesterday about the fictitious vehicle. Before I do that, though, I want to give you some practice using a method of thinking aloud while you work on a problem.

Think-Aloud Instructions

I am interested in what you think about as you work on a task that I will give you. I'd like to get as accurate a picture as possible of what is going on inside your head as you solve the problem. To do this, I'd like you to think out loud as you work. What I mean by think aloud is that I want you to tell me everything that comes into your head from the time you first hear the problem until you finish. You should talk constantly. Don't try to plan out what you say, or try to explain what you're saying. Just report your thoughts, images, etc.

This is a different kind of speech than we're used to, because most of us try to think before we speak. I'm going to ask you to forget that caution for the moment, and to say whatever comes into your head. Just let the thoughts flow out of your mouth. Speak as continuously as possible; don't hold back hunches, wild ideas, guesses, or even "I'm drawing a blank"; describe any images that might come to mind. Don't worry about speaking in complete sentences. Just get into the habit of reporting what you're thinking at the moment, rather than thinking for a while and then describing your thoughts.

This can take a little practice, so let's try some practice problems. Multiply 24 X 36 in your head. (Prompt as necessary to keep subject talking audibly, and reporting vs. interpreting. Mention any gestures or non-verbal signs that subject makes.)

If subject made gestures, say: **That was great. Notice that I sometimes mentioned what you were doing. This is because I'm going to tape record what you say, and these hand movements won't show up. So, don't be bothered if I repeat what you're doing during the task. It's just to have a record on the tape.**

Great. Let's try another practice one. How many windows are there in your parents' house? (Experimenter should prompt, as before. If subject still is not entirely comfortable with thinking aloud, give this practice item: **Name 20 animals. I'll count them for you; you only need to name them.** When subject has finished, say:)

Do you have any questions? Good, let's get on with the main task.

Appendix III: **Design Summaries**

G1A Design Summary--Principles Task

(16 design episodes + 9 review episodes)

G1A will begin her instruction with the topic of the sun, using that as the "unifying principle" for all energy instruction. All energy forms eventually "come back to" energy from the sun, and G1A will reiterate this theme throughout the instruction. She will "show" how visible light is converted into chemical energy in photosynthesis. She will go from this topic into solar energy and photovoltaic cells. From there she will turn to the topic of stored heat, as in water-stored solar heat. Then she will "go into" climatic effects, such as the wind. Wind-generated electricity, and then electricity in general, will follow. Electricity will include the topic of circuits. This will lead to batteries and stored energy. G1A will then address in her lesson chemical energy and redox reactions in relation to plant energy and batteries. From chemical energy G1A will move to nuclear energy and the topics of nuclear safety, breeder and burner reactions, fission, and fusion, the last of these which she will tie into instruction about the sun. Nuclear energy will lead to the purification of energy and energy transformations, such as from nuclear to electric, and from electric to work or mechanical energy. The instruction will then focus on machines and on potential and kinetic energy. (EP 4,5)

At some appropriate point, G1A will instruct her students about conversion of heat energy to electricity by the burning of plants, coal and oil, and through the use of steam turbines. From steam turbines she will segue into hydroelectric energy, and might even address tidal energy. She will also talk about renewable and nonrenewable resources. (5) When discussing converters, she will simultaneously discuss inefficiency as the loss of energy in the forms of heat, friction, etc. in the conversion process. (EP 18) She will also address the transportation of energy and related safety issues, and the purification of energy. (EP 2)

G1A will explain the VST 2000 in terms of a plant using chloroplasts for energy storage. (EP 12) G1A will use the transition back to plants to give the curriculum a more life sciences "bent." She will use the vegetor to illustrate that energy from the sun is stored in chemical bonds and then converted back to energy by plants and by consumers . She will "get into" the various levels of consumers. (EP 13) Then she will "show the body as a machine." (EP 14)

G1A will use the VST 2000 tutorial in various ways throughout the lesson. The Tablograph will be used to illustrate a nonrenewable energy source. The Vegetor will be useful in instruction regarding renewable energy sources, photosynthesis, batteries, and chemical reactions. The VST 2000 will in general be useful in illustrating principles about solar energy and plants, about photovoltaic cells and light, about machines and work, about potential and kinetic energy, about energy transformations, about the storage and release of energy, about redox reactions, about electricity, and about the physics of circuits. (EP 3,7,10,11,12, 14) The VST 2000 tutorial will be used to illustrate the general principle that without the sun no further energetic activity can take place. (EP14) It will be used to demonstrate the different energy sources it uses, and how these can be translated into a standard form of energy, electricity, which is used in a physical motor that changes it into mechanical energy. (EP 17)

G1A will have one or two students to each VST 2000 tutorial in her instruction. She will have the students manipulate the various switches and "have them come up with a few basic principles about what's going on" in a "discovery lesson" style. (EP 6,8)

After the students have played with the tutorial for a while, G1A will have them share their ideas about it in a brainstorming session. She will give them certain ideas about power for the various energy sources and then send them back to the tutorials for half a period of more experiment and play. She will then assign the students the tasks of building circuits themselves and of going through the text windows, checking the answers themselves and going back for review if their answers are wrong. (EP 9,10)

G1A will modify some of the questions in the tutorial to be less vague. She will also trim redunancy out of the text and streamline it to make it more accessible to high school students. (EP10) Throughout the instruction, G1A will refer to the tutorial when needed, probably having it available on a large display screen. (EP14) G1A would like to be able to highlight the wires in the tutorial circuits to show the flow and stoppage of electricity within the circuits. (EP 15) G1A would also like it if the tutorial indicated the amount of energy being used and remaining at any given time . This would allow the students to calculate efficiency levels and do more "hands on" work with the machine, and also allow for instruction in kinetic energy, for problem-solving sessions and for simulation labs. (EP 19,20,21, 22)

G1A will use materials additional to the tutorial if possible. She will bring in a device to demonstrate the energy available in ordinary sunlight, and will bring in small acid battery, having the students relate these to the principles addressed in the course. (EP 24,25)

G1A Design Summary--Operations Task

(9 design episodes + 5 review episode)

G1A will start the instruction in VST 2000 operations with some basic theory about energy. Beginning with a discussion of the sun, she will show the students the vehicle, pointing out the "solar part," the switches and the various energy sources. She will correlate the VST 2000 to cars, talking about the energy bar as if it is a gas tank. (EP 3) Her general tour of the vehicle will also include showing the students the motor, the wheels, the steering mechanism, etc. After completing the tour, G1A will ask the students if they believe that sunlight can be changed into a useable energy form. She will then have them feel the difference in heat absorption between black and white plastic sheets she had placed in the sun before the start of the tour. She will explain the difference, and relate the heat absorption to the creation of electricity from sunlight by the solar pack. She will tell the students that they need sunshine as a starter for the vehicle, and then explain a bit about the switches and the purifier. (EP 4,10)

G1A's next topic for discussion will be the storage of energy in the energy bar. She will show the students how the energy bar is a rechargeable battery, and demonstrate the use of this energy by actually operating the vehicle from this power source. She will discuss the disadvatages of the energy bar as a power source, and show that the Tablograph is a more constant source of energy because it does not have to be recharged periodically. (EP 5,10)

G1A will then take the vehicle to an indoor location to demonstrate how it operates when there is no sunshine. She will indicate that the Purifier always has to be running. In this case, the energy bar will be used to run the Purifier while the Tablograph will be used to run the vehicle and to recharge the energy bar. G1A will show the students how energy in the vehicle can be converted from one form to another and that energy from any of the three sources can be used to run the vehicle. (EP 6,10)

Next G1A will have the students learn about the switches. She will teach them some basic circuit theory so that they know that circuits always have to be complete. She will have the students understand what each of the switches does and have them devise their own scheme for making the circuits work. She will give the students various problems to solve using the switches in the vehicle, and will take safety measures while doing this. (EP 7,11)

G1A will give the students instruction in physically starting, stopping and steering the vehicle. (EP 8) Much of the information will be presented in a "hands-on" manner. G1A will probably bring in a chalkboard to "draw out" some of the inaccessible and relevant portions of the vehicle, or she may hang pre-made drawings for this purpose. (EP 12)

The students will be given take-home assignments and will be asked to write about what they are learning during the course of the instruction. (EP13) For a final exam they will be asked to write up a plan to keep the vehicle operating continuously for a 36-hour period under the variety of circumstances that this would present. (EP 8,13)

G2B Design Summary--Operations Task

(18 design episodes + 26 review episodes)

The first thing G2B will do for the operations task is tell the students that the VST 2000 is a new earth vehicle and give them a "general introduction to the machine." (EP 2,21) His introduction will include some specific objectives for the lesson, such as learning "how to get the energy through the circuits." (EP 22) Then he will "talk about the [energy] system," discussing the "three different parts to it--the Tablograph, the Vegetor, and the Impulse Purifier." After giving background information on the energy sources, G2B will discuss the various settings for the switches. (EP 8) After addressing these topics, G2B will "spend the greatest amount of time" on having the students learn how to operate the VST 2000. (EP4,5) G2B assesses that the "whole game" in learning the VST 2000 is being "able to use the different types of power and recharge the energy bar." (EP 14,38) Ultimately, the students "need to know how to do all the little things." (EP 38)

G2B will teach this material in written as well as visual form, drawing diagrams for each of the four functional settings of the switches. (EP 10,18,31) The diagrams will be presented on the blackboard and on the overhead projector. (EP 10,31) G2B might also have the students trace the lines through which the energy flows for each setting of the switches. (EP 14,38) He will talk about the visuals, "trying to make [them] logical." (EP 15,38)

G2B will modify the tutorial to present a clearer overview of the lesson than is now provided. (EP 22,27) He will have the students tutor each other in peer groups after they have gone through a section of the instruction. (EP 33) G2B hopes that the students will be presented with or devise mnemonic devices to help them remember what the various letters labelling the switches signify. (EP 35) He will suit the classroom activities to the abilities of the students, perhaps inviting the students "up to the board" if their language skills are weak or lecturing the material to them "straight out" for advanced physics students. (EP 37) G2B will have the students work on the four tasks presented at the end of the tutorial. (EP 43) He will also ask the students questions "that would be helpful, or...that attack misconceptions" in relation to, for example, the energy bar, the scanner, etc. (EP 44)

G2B Design Summary--Principles Task

(5 design episodes + 14 review episodes)

As an overall objective for the principles instruction, G2B will give the students activities from which through observations they can make hypotheses and draw conclusions. For example, they can observe what happens to energy flow in parallel and series circuits when each is respectively broken. (EP 14,15)

G2B proposes fossil fuels and pollution as good topics for instruction in the principles task. He will also "tie in" energy storage, (EP 2,13) energy conversion--including potential and kinetic energy, and the transportation of energy, including electrical circuits. (EP 3,7,11) Energy conversion as a topic leads to many activities for the students converting between different forms of energy. (EP 3) These would include generating electricity with magnets, running this through wires on circuit

boards, and converting electrical energy to heat energy or light energy. (EP 10) In terms of purifying energy, the instructor could talk about the distillation process. Without kits which the students could use to refine oil samples, for example, the area of the recovery of fossil fuel can be taught only in lecture style, which is very dull. (EP 9)

G2B might use the tutorial for the instruction, but he would rather spend class time talking about energy systems that are being developed in the world currently. (EP 4) If G2B has a sufficient amount of tutorial terminals, he will have the students go through the task together in groups. (EP 5) G2B might "spend a whole day finding out what the students know about energy," giving them pretest questions like, "How do we get electricity?" (EP 7) To present boring but important topics such as, "Where do we get our oil?", G2B will have the students do research projects and present them to the class. (EP 17) This kind of research and thinking addresses social values that the students are developing. (EP 16,18,19)

G3A Design Summary--Principles Task

(51 design episodes + 6 review episodes)

Overall, G3A will organize this instruction around the three types of energy sources used by the VST 2000: solar, vegetable matter, and nuclear. (EP 3,4) G3A will begin by familiarizing the students with each part of the machine. He will follow the format of the tutorial's "review box." At this point, he will not get into the specifics of how the various connections of the switches work. This part of the instruction will last for one class period. (EP 6)

For the remainder of the week, G3A will go over the specific sources of energy, spending one day each on solar, nuclear, vegetable, and other types of energy. (EP 7) At the end of this section, G3A will assign a research project to the students in which they will study in depth one of the topics introduced this week in class. (EP 9)

After sources of energy, G3A will go into types of energy, beginning with potential energy. He will spend two days on this topic. (EP11,12) G3A will direct one or all of the students to something like the San Francisco Exploratorium or the Boston Museum of science where there are exhibits with balls on roller coaster tracks that demonstrate the conversion of potential into kinetic energy. (EP 13) A lab like this could be set up in the classroom, perhaps on the second day of this section of the instruction. As part of this lab, G3A will give the students the equation relating force and energy and distance. He will ask the students for other examples of the conversion of potential to kinetic energy. (EP 14) After this introduction to kinetic energy in the lab, G3A will spend a day on the subject in class. (EP 15) The storage and extraction of energy will be introduced as part of the lesson on potential and kinetic energy. (EP 22)

Next, G3A will have the students relate the types of energy in the machine to the various parts of the machine in a short, written exercise. (EP 16) The assignment will focus on having the students hypothesize about which energy forms in the machine are potential and which are kinetic. (EP 19) After this, G3A will spend one day introducing the VST 2000's forms of energy: raw, purified, and the two types of potential and kinetic energy. The written assignment for this section will be on how and why forms of energy must be converted. (EP 21) At this time, G3A will stress to the students that energy is not the same thing as electricity; the two are not "equal." (EP 45)

On Friday of the second week of class, G3A will "tie" the material discussed so far "into sources"; i.e., he will identify what form of energy different energy sources represent, such as the kinetic energy in running water. (EP 24) At the beginning of the next week, he will talk about how to change energy from one source to another, specifically from potential to kinetic. (EP 25) He will then prompt the students into bringing up the subject of energy storage by asking them if kinetic energy can be changed into potential energy. (EP 26) If, at this point somebody asks what energy is, G3A will assign them to write a research paper on this. (EP 28)

G3A will then turn to the topic of solar energy. He will talk about how the energy is extracted and put into usable form, using the VST 2000 as an example. (EP 27) He will describe the solar cell, and relate this to the use of solar energy in space stations. He will also describe the sun's enormous energy potential and the cleanliness of solar power. (EP 29) G3A will draw a distinction between actively collected solar energy,

such as with a solar cell, and passively collected solar energy, such as with a water tank set in the sun. (EP 31)

Next, G3A will next spend one day addressing nuclear energy. (EP 31,36) He will start with the topic of fission, using the examples of the VST 2000 and nuclear power plants. He will explain that nuclear fission power is limited by the availabilty of fissionable materials, such as uranium. It also produces hazardous wastes, a topic that some student might want to research. (EP 35) Nuclear fusion, on the other hand, is virtually clean and unlimited in its potential. G3A will provide a basic description of fusion and its properties, including its currently limited practicality. (EP 38) He will tie the topic of nuclear energy into that of the Tablograph. (EP 42)

G3A will spend the next day on to the topic of fossil fuels. He will introduce the different types--oil, coal, natural gas--and tie these in to discussion of the Vegetor. He will also give a paleontological description of the origins of fossil fuels. (EP 39,42) He will briefly address alternative energy sources: hydroelectric, ocean temperature differentials, tidal power, geothermal energy, etc. Students will be encouraged to research some of these topics if they do not yet have a research topic. (EP 40)

The class will then turn to the subjects of the transportation and conversion of energy. (EP 42) G3A will start by spending one day on the forms of transporting energy: wires and pipes. He will discuss this in terms of getting the energy to where it is needed. G3A will explain that energy is transported for reasons of convenience, so that it can be converted and used. For energy conversion/purification, G3A will term it "get it in the form you want it." Here G3A will "refer to the Vegetor." (EP 47)

G3A terms the next topic "representation." By this he means basic circuits, or basic energy diagrams. These include wires, "crossings," switches, sources--including input and output--and converters. (EP 48) He will spend a day going over this. (EP 49)

G3A will present the students with a variety of basic machines whose parts he will label either on a overhead transparency or a computer screen. He will compare these to the VST 2000. (EP 54) G3A will have the students identify energy sources, such as stoves and heated pools, in their everyday lives. In terms of methods, the course will be characterized more by conversations, dialogues and "hands on" activities, such as labs, than by lectures. (EP 55) Materials for the course will include diagrams and pictures as well as a stereo system with its components detached. He will relate the components to the diagrams of circuits he presents. (EP 56) G3A will determine the instructional methods and materials more specifically at a later time. (EP 54)

Questions and problems in the course will range from the very specific type presented in textbooks or for homework to more general topics, such as those being researched by the students for their unit project. G3A will present the students with the problem of hooking up a light bulb, or some other simple project for building connections. (EP 57)

G3A Design Summary--Operations Task

(7 design episodes + 6 review episodes)

G3A sees the tutorial as the best way for teaching students the operation of the VST 2000. It provides simulated "hands on" experience, and allows students to proceed with the instruction at their own pace. (EP 2,3)

G3A will hook up a TV screen or devise some other means of providing for the whole class to view the tutorial monitor as he goes through some of the exercises and shows the students how it works. After such an introduction, the students will each go through the tutorial themselves. Once the students have learned the parts of the machine, the switch connections, and the means for powering the motor from the three energy sources, they will be able to try operating the actual machine. This will be a helpful prerequisite to actually operating it.

G3A will have an operational VST 2000 available for the students to observe and handle as they are studying the machine on the tutorial. (EP 2,12) He will lecture in conjunction with the tutorial presentation, restating, elaborating, drawing additional diagrams, and asking the students to describe the relationships between the parts in their own words. (EP 5) Schematic references of the VST 2000 and its parts will accompany the tutorial. (EP 6)

G3A envisions two improvements to the tutorial presentation. First, he will have ways of showing the individual parts of the machine separartely and in detail. (EP 7,11) Second, the tutorial will include a video game in the "hands on" section that will allow the students to keep score and improve their understanding and skills. This will serve to enhance motivation. (EP 10)

The students will solve problems in identifying the parts of the machine and determining how the switches should be set for a desired outcome. G3A will give the students "blank copies of the schematic" on which to work these out. Some of these problems will be assigned by the instructor and others wil be created by the students as challenges to eachother. G3A will have the students form competitive teams to solve these problems. (EP 13)

G4B Design Summary--Operations Task
Vera Michalchik, 1/14/90

(50 design episodes + 11 review episodes)

G4B will approach the operations of the VST2000 in a step by step fashion, "start[ing] things at a basic level, and then gradually add[ing] on" (EP 50). G4B will begin the instruction by breaking down the information into basic categories. She will start by defining a motor and the parts of a motor, and she will proceed to describing the differences between local and non-local, or internal and external sources of energy (EP 1,2). She will include in this discussion an explanation of "how to convert energy in its raw from to usable energy," noting that some initial power source is necessary in order to get the system going (EP 9, 16). She will also define and discuss, at this point, energy conversion and purification (EP 16). From here she will move to a description of the three different types of energy used by the motor in the VST2000 (EP 4,5). She will use a simple diagram with three big circles with lines leading to a motor to illustrate this "bigger picture," and will then take each source--the Vegetor, the Tablograph, and the Impulse Purifier ---and describe each one in detail (EP 6,7).

She will begin the detailed description with the Impulse Purifier, talking about "how the Impulse Purifier uses solar energy to give energy to the system that will eventually propel the motor" (EP 7). The class will focus on details of using the "solar system" such as turning on and off the power, and will study the pathways the energy follows and the need for the energy to be purified in order for the system to not break down. This will occupy a lot of time (EP 12). G4B will explain the Impulse Purifier and then allow the students to figure out the details for themselves or at least ask questions and engage in some activities before moving on to the next topic (EP 13).

G4B will tell the students that from the Impulse Purifier, the energy is sent to the motor (delaying discussion of the selector switch and its settings). She will show the students an enlarged diagram of the solar energy system of the VST2000, with a depiction of the energy from the Impulse Purifier going straight to the motor. Afterwards, she will have someone in the class explain this back to her (EP 18). G4B will provide an example of solar energy powering an appliance useful in the students' lives, such as a solar calculator (EP 19). The students will then complete an exercise wherein they will trace the energy pathway on a skeleton diagram, after which the class will discuss who got the problem right, where and why the others went wrong, etc. (EP 20).

The next topic for the class will be the Tablograph (because, relative to the Vegetor, its less complicated) (EP 21). Again, the starting point would be a general diagram, either on the board or on a poster, that shows the energy source with the energy flowing directly to the motor (EP 22). After defining the Tablograph, G4B will discuss the halt and produce functions, explaining that the H and P are analogous to the plus and minus functions on the Impulse Purifier (solar pack) (EP 23,26). Unlike the Impulse Purifier, which depends on the sun to be shining for energy, the Tablograph has a constanly available source of energy. All one need do to access it is set the switch to P (EP 24,26). The needle of the Tablograph is analogous to the photo receptor; it collects energy from the source, sending it to the converter for transport to the motor (EP 25,26). After this, the students will fill in another skeleton diagram, maybe with one person sketching the energy pathway on the Tablograph diagram at the board (EP 26).

Next, the class will turn to the Vegetor, relating its name to the vegetable matter which comprises it (EP 29). First, the class will discuss the differences between the Vegetor and the other two energy sources: it is synthetic, it needs to be recharged, and it uses a scanner head rather than a photo receptor or needle to collect the energy and send it through the converter to the motor (EP 29). The students will, at this point, need to learn how to recharge the Vegetor, which process will begin with G4B asking the students how they think they can recharge it. (G4B anticipates that the students will come up with the idea of getting energy from another source and putting it back into the Vegetor for use in operating the VST2000) (EP 29). Next, G4B will discuss with the class the differences between the H and P and the R setting of the Vegetor operating switch. In conjunction with this, G4B will discuss in detail the movement of the scanner head, and what its various positions and directions indicate. G4B will draw a line that shows the flow of energy from the scanner head to the converter as it moves across the bar picking up energy (EP 30). This section will end with a quiz covering the information on all three energy sources (EP 35).

G4B will then address the topics of the purifier and the switches (EP 31). First, G4B will explain the VST2000 energy systems without introducing the notion of a purifier. Then, after explaining why purification is needed, she will ask the class whether it would be more efficient to have a purifier for each energy source, or to have just one purifier for all three sources. After establishing the one-purifier model, she will ask how the energy from the disparate sources could be directed to this purifier, developing a question-and-answer method of arriving at the concept of switches for this (EP 32).

First, in explaining the switches, G4B will let the students know that they will have to decide on which type of energy they wish to have purified; the selector switch can direct energy to the purifier from only one source at a time (EP 37). After this, she will talk with the students about the selectivity and discriminating quality of the switching system, comparing it to valves in a heart. Once the students understand that only certain things are allowed to pass through the switches at certain times, she will explain that there are rules for how this passage is allowed to occur; for example, there are certain switches that must always be off, certain that must always be on, and certain combinations to follow for desired effects (i.e., for energy from particular sources to pass through the purifier to the motor) (EP 38). She will illustrate this with specific examples, such as the TaO setting for the Tablograph aand the PrO setting for the Purifier (EP 39).

From here, G4B will present the students with three problems. She will set the switches, and then ask the students if energy can pass from, for example, the Tablograph to the purifier, given this particular setting. As she changes the switch settings, the students will inquire as to what the settings mean, and this will provide G4B the opportunity to further explain the details of the switches. She wil present the students with combinations that will and ones that will not work (EP 40).

Next, the class will discuss the selector switch in terms of its discriminatory function; it will let only one energy source into the purifier at a time. G4B will, again, give the students examples of switch settings and ask the students which type of energy is being allowed to pass through, given this setting (EP 43). After discussing the selector switch, the discussion will turn to the remaining set of switches, which are responsible for the passage of energy from the purifier to the motor. The students will be told that one of the motor switches must be on for this to occur, but both can not be on (EP 45).

G4B will explain that "both of the switches have...the recharge, the off, and the motor switch" settings on them. This is because the energy can be directed in "several different ways": from the purifier to the motor, or back to the energy bar again. This establishes two energy paths for the Vegetor, and provides for "a continuous motion of having to recharge and then use the energy that's put back into the energy bar to run the motor" (EP46). Perhaps the students will go to a computer and test what they have learned on their own at this point (EP 47).

For lower level students, G4B will use the analogy of the human body to aid in their conceptualization of energy conversion and tranferrence(EP 48). In general, G4B will assign the students small group activities wherein they will make posters that diagram one of the VST200's parts and the energy pathways within these. Both the teacher and other students will offer feedback in this process, and each group will share its poster with the other groups. At the end, the posters could be arranged to represent the whole VST2000 system. G4B will offer bonus points to the group with the best poster. She will also give the students a handout with the whole system outlined. G4B will probably present the students with a written text describing the system, and then discuss the readings with them for clarification (EP 57). G4B will also probably present the students with word problems or scenarios in which they were to operate the VST2000 under a variety of conditions. She will have the students discuss their solutions in groups and present them (EP 60). G4B might even, after all the explanation is completed, give the students a diagram, ask them to study it for a bit, and then test them on it (EP 49).

G4B Design Summary--Principles Task
Vera Michalchik, 1/14/90

(25 design episodes + 8 review episodes)

When the students first come into the classroom for this lesson, G4B will present them with a question relating to energy, probably about the food the students had eaten that day and the energy-related consequences of this (EP 64,97). G4B will use this as a starting point to address the five topics presented in the design task: storing, extracting, converting, transferring and purifying energy. G4B will develop this beginning by asking the students what the food that they have eaten is used for, how this food becomes useful, etc. This will lead to discussion of conversion and transportation of energy. The class will discuss related problems, such as how it is that one can be energetic without having just eaten, and this will lead into discussion of energy storage. In general, the human body and its energetic processes will be used as an illustrative beginning for this instruction (EP 65).

The storing of energy leads to the topic of extraction of energy: How can one's body use the energy stored from something that was eaten yesterday? The class will define extraction together, and, during argument about the definition, students will differentiate between different shades of meaning for the term (EP 67). Then G4B will ask the class if their is any organ in the body that "takes out the impurities in the foods that we eat?" After discussing the kidneys, the class will discuss the use of energy in purification, and a definition of purification wil be discussed (EP 67).

Once the class has defined the five key terms (EP 68,97), G4B will give the students some reading materials which will help the students better understand these basic concepts (EP 82,99, 100). After this, the class will discuss other forms of energy--hydroelectric, electricity, nuclear, gasoline---and their uses--machines and motors (EP 69).

After this , G4B will present a diagram of the VST2000---three bubbles representing the Tablograph, Impulse Purifier (solar pack), and Vegetor, all with lines leading to the motor (EP 70,100). G4B will "explain to [the students] these different ways of using energy, and how each of these systems has a way of storing, extracting, converting, transporting and purifying energy." She will also explain to the class that the VST2000 will be used to illustrate these principles (EP 70).

G4B will start discussing the functions of the VST2000 with the solar energy system. Solar energy is stored in the sunshine (sic), it is extracted through photoreceptors and kept in the solar pack until it is converted (EP 73,74). It is then transported through wires and purified, before other wires take the energy to the motor(EP 67). G4B will locate each of the five main principles in terms of the visual representation of the the VST2000 component that illustrates the principle. In other words, she will point out the "visible object[s] such as a storer, an extractor, a converter, a transporter," etc. (EP 73). This will all be presented in an explanatory fashion by the instructor (EP 75).

The next topic will be presented more interactively. G4B will show the students a tablet and tell them that energy is stored in it. Students will respond to her questions by telling her that an extractor is needed, and she will then draw a needle on the board. Further questions and answer will lead to suggestions for a converter, a transport system (wires), a purifier, and use of the energy in the motor (EP 76). G4B will relate the

Tablograph to uses of nuclear energy. Discussion of other forms of energy will perhaps lead to mention of vegtable sources, which will provide the transition to talk of the Vegetor (EP 78).

Next, G4B will explain the different parts of the Vegetor and how these illustrate the five principles (EP 80,81). G4B will explain that the Vegetor is different from the other energy sources in the VST2000 because its energy gets used in degrees and can run out, so it has to be restored (EP 80). The Vegetor will be used to show "that different kinds of energy are extracted in different ways, and that some forms of energy have to be replenished before they can be extracted again" (EP 84). G4B will simplify the VST2000 diagram so that it will show that the energy from the Vegetor flows in two paths: one for recharging, and one for directing to the motor (EP 88).

G4B willl also pesent a simplified version of the switches, drawing an analogy between them and the gears of a car. Both the VST2000 switches and car gears are used to select appropriate amounts, or types, or directions of energy; it is a matter of making a selection, and channeling energy accordingly (EP 89).

The class will break into small groups to work on problems the instructor presents (EP 90,99). The main problem the students will be presented with will be about how to get energy under unusual circumstances. Students, given a hypothetical of being stranded, or on another planet, or in primitive times,etc., will have to think of ways for locating, extracting, converting, transporting, stroing, purifying and using energy. Given a cave man scenario, they might comes up with means for using sticks to create fire, or something (EP 95,96,102). Students could work in small groups, develping group working skills, and could present their answers in graphic form to the class. Both verbal and visual methods of presenting will be used (EP 99, 101,104). Ideally, at the end of the course, G4B will be able productively to ask the students to apply their understanding of the principles presented in this lesson to real-world problems that relate to energy, such as deforestation and fossil fuel use. The students could respond in terms of conservation, lifestyle, technology, or even geopolitics (EP 103,104).

N1B Design Summary--Operations Task

(22 design episodes + 8 review episodes)

N1B will focus on "just the workings" of the VST 2000 in the operations instruction, with the objective of the students being able to take the vehicle from "point A to point B" without having to worry about the "actual transactions and the conversion of energy." (EP18,23) The main emphasis of the instruction will be on "efficient channeling of energy from a source to the motor." (EP 23)

N1B will begin instruction in the operations of the VST 2000 by explaining the three power sources available for running the machine. He will describe to the students that they must turn on the power switch in order to get energy from the particular power source they choose. (EP 3)

N1B will have the students use the tutorial and scatch paper for taking notes, but will not require that they take any specific notes. (EP 4,26) He will give them outlines and also diagrams showing the alternate energy paths for the different energy source "scenarios"; e.g, the path of the energy flow when using the Tablograph instead of the Vegetor to power the machine. (EP 4,9,21,27) N1B will early in the instruction have the students go through the tutorial, "play with it for a minute," and try to get each power source working. (EP 5) Periodically, at the end of each "section," N1B will have the students "play with" the switches on the tutorial screen and complete certain tasks, showing him the path of the energy flow in the circuits they create. (EP 12,17,27,29) N1B will frequently ask the students if they have questions and encourage them to talk about things they do not understand. (EP 18,28) He will "appeal" to the students senses' and also their "reason," emphasizing the "cause and effect relationships." (EP 25)

Next, N1B will discuss the Purifier, telling the students that they do not need to worry about the "transfer" of energy [from one form to another]. (EP 6,10) They do, however, always have to turn on the Purifier power source, regardles of whether or not they are using the solar pack. (EP 6) When discussing the power switches, N1B will explain to the students the meaning of each of the letters and symbols: they all function to turn on and off the power sources. He will draw an analogy between the VST 2000 switches and relevant parts of a car engine. (EP 7)

N1B will describe to the students exactly which circuit patterns they need to follow in order to have power flowing as they would like (EP 7,8,9,10). He will tell them specific things regarding the switches, such as that if they are using the solar pack they do not need to worry about the "I" switches since those are used only in conjunction with the other two energy sources. (EP 7,24) N1B will also help the students remember the patterns by having them Associate "T" with Tablograph, "M" with motor, and the like. (EP 7,11)

After discussing the circuitry, N1B will explain to the students the important aspects of the selector switch. He will tell them that although they can have power coming in from any energy source, the engine can only "absorb" power from one source. The position of the selector switch will determine this. N1B will show the students how to switch the selector from one power source to another. (EP 9) He will then return to the subject of the Purifier, explaining to the students that energy must pass through it in order to be used by the motor. This would lead to the subject of the M part of the MOI

ports of that switch. (EP 10,11) N1B will mention that students do not have to worry about overloading the motor because of automatic safeguards against this. (EP11)

N1B will next tell the students that they can "check themselves" to see where the energy driving the motor is coming from by noting what letter appears in the motor logo. He also will tell them to keep the sun switch turned on; the solar pack can not be used at night because there is no sun. (EP 13)

After the other substantive topics have been addressed and the students have confirmed their understanding of these, N1B will begin to explain to the students the Vegetor. He will tell them that the Vegetor is rechargeable, and would show them the various settings of it. (EP 14) He will then tell them specifically how to recharge the Vegetor, describing in detail the possible power sources and switch settings. (EP 15,16,27) N1B will have them practice recharging the Vegetor on the machine [VST 2000 tutorial], and explain to them how to do this in the actual vehicle. (EP 17,27) After this section of instruction, N1B will give the students a series of exercises to have them practice running the VST 2000 and recharging the Vegetor from the possible combinations of power sources. (EP 19,20,29) He will also give them diagrams showing "direct paths" for the energy flow for these operations, giving the students a "visual idea of what the paths look like." (EP 21)

After this, N1B will take the students "out to the machine itself" and have them practice running the VST 2000. (EP 22) He will "pop the hood" and show the students the actual parts of the machine. He will have the students visualize the flow of energy through the various switches, perhaps using their fingers to point to and trace the relevant paths. (EP30)

N1B Design Summary--Principles Task

(16 design episodes + 3 review episodes)

The focus for this instruction will be on the "'whys' instead of the 'hows'," by N1B's design. He will include in the "principles" instruction what he consciously omitted in the "operations" instruction. Instead of emphasizing the switches and their functions, he will emphasize each "primary stage of energy itself": the three energy sources. (EP 1,2,17) His objective will be for the purpose of "more of an understanding instead of an application." (EP 17)

He will begin by "mak[ing] sure [the students] understand" the basics of solar energy. He will also address the basics of nuclear and battery power, because of their similarities to the Tablograph and Vegetor, respectively. He will explain to the students that the Solar Pack only transmits energy while the Tablograph and Vegetor also store it. (EP3) After this, N1B will explain that for each power source some energy has to be expended to collect or extract energy. This will lead to a description of efficiency: the relationship between what is "put in" and what "gets out." (EP 4)

Next, the instruction will turn to the issues of receptors and solar energy. N1B will use the example of a solar-powered car to illustrate the principle of conversion from heat energy to "an impulse type energy" for powering the car. (EP 5) This will lead to a discussion of conversion of energy from the other two sources (Tablograph and Vegetor) to one useful in the motor, in general a conversion from potential to kinetic

energy. N1B will ask the students to come up themselves with the reasons for the need to convert the energy. He hopes that background reading and the teacher's explanations will provide students with the ability to "elucidate some kind of answer." (EP 6)

Once the students understand the process of conversion, N1B will discuss the function of the switches. He will explain that the switches do not affect the energy, but just the flow of it. (EP 8) Next, N1B will explain the various parts and functions of the Vegetor. (EP 9) In relation to the observation that the Vegetor "just doesn't recharge by osmosis," N1B will discuss the need to use power to create power. N1B will then "go through" the channeling of energy from the machine to recharge the energy bar. (EP 9,10)

Although the energy has been selected and made available at this point, it is not yet in a form usable by the motor, N1B will explain. (EP 10) The Purifier is responsible for the conversion of energy in the VST 2000, he will further explain. N1B will have the students do background reading in the different types of energy a motor can use, and have them relate this to the type of motor in the vehicle. This will lead to an explanation of the different switches and patterns for channeling the energy to the motor (EP 11) and for channeling it to the energy bar for recharging. (EP 12) A "sidetrack" into more specifics of recharging the Vegetor will be followed by more explanation of switches and channeling. (EP 13)

N1B will not focus too much on the channeling of energy; he will concentrate on the conversion of energy from one form to another, and will draw diagrams to illustrate this.(EP 14,17) He will also set up demonstrations to show the conversion of energy using wood, fire heat, steam, etc. He will use the example of nuclear reactors and solar powered cars in his explanations of the transfer and also the "manipulation" of forms of energy. (EP 14,15)

For a "final experiment," N1B will have the students determine the efficiency of the machine by measuring and comparing the energy going into the system with that coming out of the system. (EP 15) After this, N1B will discuss the advantages and disadvantages, the appropriate times and other criteria for determining when to use the different power sources (e.g., the solar pack will not work to power the VST at night). (EP 16)

In terms of materials, the students will be free to take notes and will be given outlines and diagrams of circuits ("schematics"). The important "phases and steps" of the energy will be illustrated with the aid of an overhead projector. For activities, the students will be asked to draw energy pathways indicating at which points the form of energy changes. They will also be asked to read relevant material on batteries, solar and nuclear energy. They will also read about the material from which the energy bar is made, which could be either organic or inorganic. Students will also be asked to write about energy transfer and the pluses and minuses of using energy from each of the sources. (EP 18) The students will be asked to explain the system to N1B, and will be given problems to solve regarding the efficiency of the system. (EP 19)

N2A Design Summary--Principles Task

(14 design episodes + 13 review episodes)

In this instruction, N2A will teach the students certain general principles about science that are on the "school committee's list of things [that the students] should know when they finish the course." (EP 7) N2A will begin the instruction by determining by means of a brainstorming session what the students already know about energy. She will present the students with an outline of and general introduction to the course. (EP 8)

The first two topics N2A will cover are the extraction and conversion of energy. N2A will base this section of the instruction on the idea that basic forms of energy will not make a vehicle run without being extracted and converted to a usable form, and that this requires some sort of a catalyst. (EP 12,17) Energy will not spontaneously power the machine. (EP 17) Specific to the VST 2000, N2A will make sure the students understand that energy from only one of the various original sources can be used to power the machine at any given time. (EP 16)

Next, N2A will address the transportation of energy, which involves getting the energy that has been extracted and converted to where it needs to go. (EP 13) The students will learn that only electrical energy can be transported in this system and that it will flow in only one direction in the circuit. They will also learn that, although there is overall conservation of energy, there is energy lost in the form of heat to the outside environment from the machine. So, not all the energy that starts off at point A arrives at point B. (EP 19)

After covering the extraction, conversion and transportation of energy, N2A will discuss energy purification: getting the energy from a crude and contaminated into a clean and useable form. (EP 13.5,20)

N2A will address energy storage last among the topics because, although it is important, "it's not a necessary thing to make an engine run, or a machine run..." and "it's not in the scheme of the actual machine,...[not] in the machine itself." (EP 14) In addition to discussing storing energy in a chemical form in batteries, N2A will emphasize the importance of storing solar energy as one of the big concerns for the coming century. She will "make sure [the students] understand that that's a very important aspect of the future that they have to think about."(EP 21)

N2A will have actual machines and actual energy sources, within the limits of practicality, in the classroom. (EP 9,23) She will show the students how to convert energy from the chemical energy in batteries to electrical energy, and other such simple conversions. She will demonstrate energy transportation with the aid of electrical circuits and light bulbs. She will use voltmeters or ammeters to measure the loss of energy. She will also use batteries and solar cells to show how energy is stored and can be extracted. The students will work through experiments to obtain "information" first hand. (EP 23) They will have "hands on" experience with "anything that they can relate to in the real world." (EP 26)

N2A would use a textbook for this course if it were suitable. (EP 24) Either in handwritten notes or on the blackboard, N2A will provide her students with a written version of what she is covering. (EP 25)

N2A Design Summary--Operations Task

(4 design episodes + 11 review episodes)

N2A will begin the operations instruction with an introduction stating that there are three different forms of energy that can be used to run the machine: the Solar Pack, the Vegetor, and "the other one" [Tablograph]. The operations instruction will be designed solely for the purpose of the students being able to actually run the machine. (EP 2,6) Once she has established that only one power source can be used at a time, N2A will "go through" each of the power sources and tell the students exactly what needs to be turned on in order for the machine to run. (EP 3,4,5)

N2A will have the students get "hands on" experience in using the switches properly to produce the desired effects. For their reference while practicing, N2A will give the students handouts showing or describing step-by-step how they should set each of the switches and operate the vehicle. (EP 7,12,14) But this is not certain; N2A might have the students play with the machine and materials until they figure it out for themselves. (EP 11,12,14) N2A will provide the students with a computer tutorial and an actual VST 2000 for practice. (EP 8)

N2A will evaluate the students on their operation of the vehicle without the benefit of written or verbal instructions. (EP 7) Problems and questions will relate strictly to the specific steps for the operation of the vehicle and how the students have succeeded in getting it to run. (EP 13,14,15) There will be "no general discussion on energy, or anything like that." (EP 13,15)

N3B Design Summary--Operations Task
Vera Michalchik, 1/17/90

(24 design episodes + 14 review episodes)

N3B will start this instruction with an overview of the VST2000, describing what it is, how she learned about it, why it is unique, what it does, how it is important to their lives. She will then show the students the machine (EP 2,25,26). Then, she will give the students an introduction to the three energy sources--the Vegetor, the Impulse Purifier (solar pack), and the Tablograph (EP 4, 28). After this, she will briefly discuss the two wiring systems, and relate this to the functioning of a car (EP 3).

N3B will use a table to compare and contrast the characteristics of the different energy systems---e.g., where the raw energy comes from, what kind of energy the system produces, what type of extractor is used. She will set the table up for the students (EP 6,36).

At this point, N3B will demonstrate the operations of the machine for the students, starting with the Tablograph. She will also give the students a flow chart that traces the path of the energy from its source through the switches to the motor. The appearance of the letter identifying the energy source is also an indication that the motor is running, she will explain (EP 9, 28, 36). After the demonstration, N3B will orient the students to the details of the energy system by elaborating on each of their subcomponents, such as the converters (EP 10, 28).

N3B will then have the students play with the tutorials, each student getting "a feel" for the switching (EP 11, 28,37). The students will be given enough time to "figure [things] out" on their own (EP 13). The students will be assigned to get the Tablograph to produce energy, based on their brief observation of the instructor and their own exploration, with some help from the flow diagram (EP 14). She will circulate through the class offering help but will not tell the students how to solve the problem (EP 15,38). N3B will not proceed until all students have solved this problem (EP 30).

After the students have discovered how to operate the Tablograph, she will assign them the solar pack, noting some of the differences between the two systems (EP 15, 31). These include, primarily, the fact that the solar pack can not be run at night, and that the energy in this systems does not pass through an I switch (EP 16). She might ask the students to note the missing component . N3B will not spoon feed this section of the instruction to the students (EP 31).

Next, the students will have to figure out how to operate the Vegetor. She will mention that the machine in general is advantageous for its multiple energy sources, that the Vegetor is more complex although substantially the same in relation to the other energy sources, and that the Vegetor can be recharged from the other energy sources, but she will not explain to the students at this point how to recharge the Vegetor. She will wait to show the students how to recharge the Vegetor after they have depleted their Vegetor energy. She will then show them how to recharge combining the energy sources, helping the quicker students first (EP 17,18, 33) But if this method regarding the recharging does not work, she will alter her plan the next time she teaches the lesson (EP 33).

N3B will have the students determine the other switching combinations after she gives them one example. They include combinations of running the machine and charging the Vegetor (EP 20, 21). She will also ask them to figure out the switching combinations

for themselves, for such set-ups as running the machine on the solar pack while charging the Vegetor (EP 21,33). She will also have them note which combinations will not work (EP 22, 23,34). Once some students have solved the problems themselves, N3B will have them go and help the slower students (EP 23). All this should be thoroughly drilled into the students (EP 34)

N3B will conclude the lesson by reviewing the features of the machine (EP 24), including the advantage of not having to recharge the Vegetor from external sources (EP 35).

N3B Design Summary--Principles Task
Vera Michalchik, 1/18/90

(15 design episodes + 4 review episodes)

N3B will begin this instruction in the way she began the operations instruction: with an general introduction to the VST2000 and time to learn the workings of the machine through hands-on work with the tutorial. After the students have mastered this, she will begin with discussion of the principles, starting with stored energy (EP 40,42, 55). N3B will describe energy storage in terms of potential energy, stating that "it is basically energy that is waiting to happen." She will use the examples of energy that is chemically, gravitationally, and "atomically" stored (EP 42,44).

N3B will then address the topic of extraction by drawing the distinction between forms of energy that are easy to access and those which require special tools--such as a needle--"to pick it up." N3B will cite electricity as a case in which the energy has to be pulled out "from the bonds" (EP 45). Extraction of energy also takes place in the burning of things--fire extracts energy from the existing chemical bonds. Additional examples include the heat energy of the sun (EP 47).

The next part of the process, as N3B will explain it, is getting the energy into a usable, "unified" form. She will use the example of a steam engine with its boiling water and turbines to illustrate the conversion of energy from a "strange" form to a productive form. A dam functions to fulfill the same objective. The dam turns the potential energy of the water situated up high--a useless form of energy--into electrical energy. N3B will also use these examples, and will have the students generate some of their own (EP 47,49).

Next, N3B will get the students "tied into" the idea of the transportation of energy by using examples from shared experience. Power lines would serve as a meaningful example of this. If, at this point, the students need relief from boredom, the discussion could include the topic of eletrical shock (EP 50,51).

N3B might use the example of international voltage differences and the need to use adapters when travelling to illustrate the idea of energy purification. She would ask the students if anyone had travelled to Europe, and ask those students to recount hteri experiences in this regard (EP 52).

N3B will tie the "thing" (presumably the VST2000) into the lesson as an example at each "level"--that is, in relation to each of the principles discussed. She will do this at the point where she discusses the real world consequences of the principles--sometimes starting with the principles, sometimes starting with the examples. The presentation will take place in a lecture format, with the instructor asking the students questions about their real-life experiences and about examples of the relevant principles. N3B might have the students work in groups. She will bring in some realia and visual media to show the students what it is she is discussing, e.g., a small steam engine, slides of a nuclear power plant or dam, etc (EP 55,56). N3B will give the students homework assignments that require that they visit the site of some kind of energy-producing facility, such as the Altamont windmills, and write up a description of this. She would leave the asssignment mainly open-eneded, but will also have the students trace the path that energy takes from its source to its consumption--e.g., starting with the wind itself. This will be part of the question and problem aspect of this instruction (EP 57).

N4A Design Summary--Principles Task

(21 design episodes + 4 review episodes)

N4A's overall goal for the instruction is to expose students to problem-solving using the computer tutorial (EP5), and then have them apply that knowledge as an analogy to understand later topics on scientific principles. (EP22)

He assumes that the previous unit was on physics, and that students come into this instruction with knowledge of simple circuits. (EP4)

This unit will last for five days (Monday through Friday), with a project extending over the week-end and finishing up the following Monday. (EP8) Class periods are 50 minutes long. (EP9)

On Monday, he will give them an overview of the week, and tell them that they will by doing a project. (EP16) They will review basic circuits and circuit diagrams. (EP8, 13) As an advanced organizer to the VST tutorial, he will present a fictitious tutorial on the board. (EP4) Then he'll introduce the VST: he'll ask them what different energy sources they know of, and give them an overview of the machine, showing the diagram on an overhead. (EP13) Then (EP15), he'll provide a transcription of the tutorial's text as a handout for them to read overnight. (EP4, 15)

On Tuesday (implied), he'll explain (EP15) that they will be working on the tutorial (EP2) in pairs (EP4) for the next two days (EP11). He'll give them basic instruction on how to use the tutorial: how to use the mouse; how you click the button; how you go back. Then, he'll ask for questions and help them out, before setting them loose on the tutorial for the rest of Tuesday. (EP15) While they are working, he will be available for them. (EP24)

On Wednesday, he'll ask if they had any questions or problems from Tuesday. (EP15) He'll tell them that if they finish early, they should skip ahead to browse (EP16) the next unit on more advanced circuits (EP12). Then, he'll set them loose on the tutorial again. (EP15) If there is time at the end, they could brainstorm about what materials they might need for their projects, or else they could do this overnight. (EP16)

On Thursday, they'll start working on their projects. (EP16) Their assigment is to make a model of the VST and market it. That is, create an advertisement or sales pitch to convince someone of its strong points, then try it out on a family member or friend to see if they can convince them that it's a real machine. (EP6) They will have two days in class to work on their models. (EP13) He will bring some materials to class, give them some suggestions, and ask them for suggestions. (EP16) While they are working on their projects, he will be really available to pay attention to them. (EP24)

On Friday, they should finish their models. He'll assign them homework for the week-end: to design their marketing strategy and try it out, working in the same pairs in which they did the tutorial. (EP16)

The next Monday, in class, they'll present their marketing ideas, and tell what happened when they tried to convince someone. If there is time left, he will do a brief introduction to the next unit, which will begin on Tuesday. (EP16)

The next unit will be on more advanced circuits. This will be followed by a unit on trouble-shooting, which will involve problem-solving. (EP12)

N4A Design Summary--Operations Task

(6 design episodes + 1 review episode)

N4A plans initially to tell the students that the reason they are "there" is to learn how to use the VST 2000. After introducing them to the basics of the machine and "how they [are] going to learn it," N4A will have the students "do the tutorial" as many times as they need to in order to learn it. Once the students become "confident enough" and, in N4A's estimation, ready to do so, he will have them practice on the "real machine."(EP 1) The training will take two weeks and will be "straightforward," including a lot of drills and not a lot of "fun and games." (EP 4) In addition to using the tutorial and the actual machine, the students will receive instruction in the form of lectures, handouts, homework assignments and class discussions. (EP 7)

N4A will expand the use of the tutorial to include tasks additional to the three basic tasks now presented. He will add tasks"where something [goes] wrong," ask the students "questions that they [will] have to think out one step further," and "probably run them through some troubleshooting also." He gives examples of these types of advanced activities: "us[ing] the Tablograph instead of the Vegetator, versus the impulse purifier at various...times"; starting the machine when there is no impulse energy going to the purifier, or when the motor is not running. (EP 2)

N4A will not require the students to learn how to fix the VST 2000. (EP 3)

After the students understand through use of the tutorial how to work the VST, N4A will have the students"go over to the [real] machine." What activities the students did here would depend on the kind and amount of feedback the students would get from the control panel: the needles and light switches and diagrams, etc. (EP6)

Appendix IV: **Subproblem Graphs**

Figure IV-1
Subproblem type and duration as a function of episode number for transcript N1B-Operations.

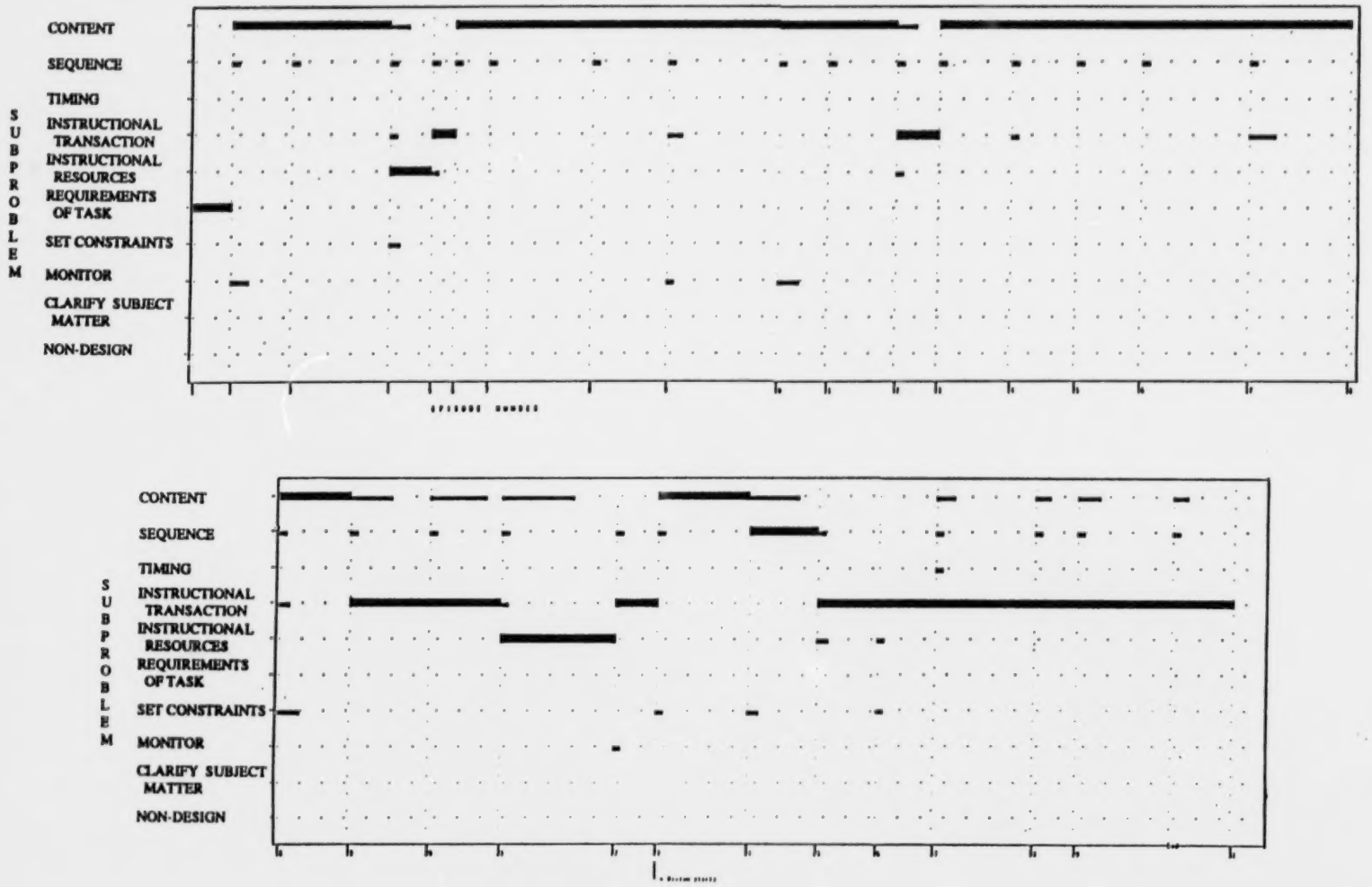


Figure IV-2
Subproblem type and duration as a function of episode number for transcript N2A-Principles.

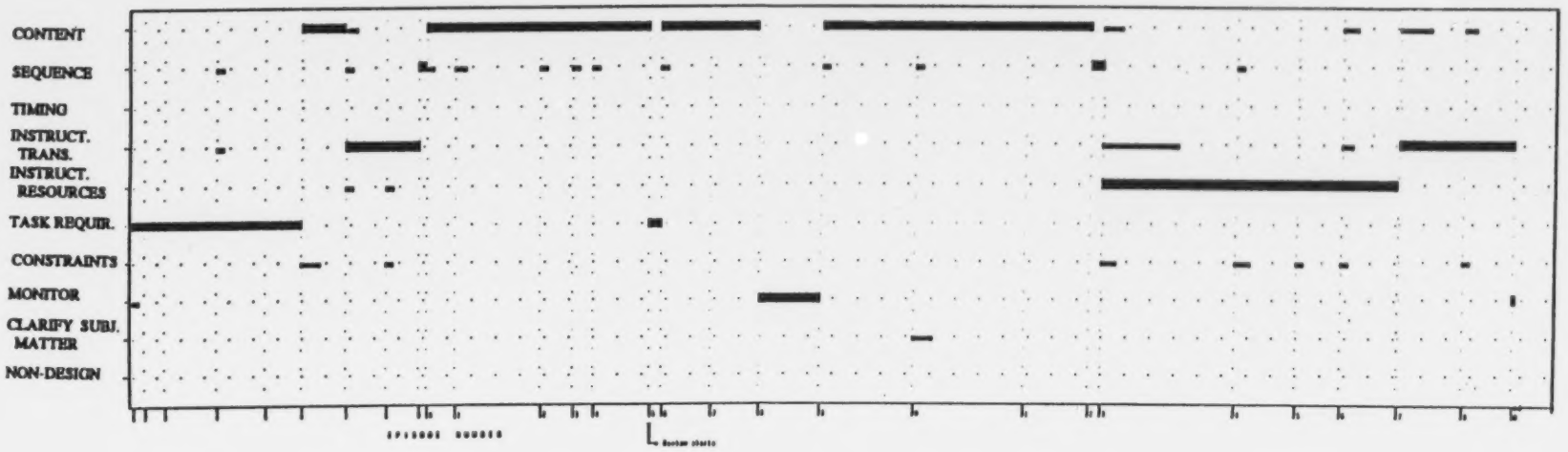


Figure IV-3
Subproblem type and duration as a function of episode number for transcript N2A-Operations.

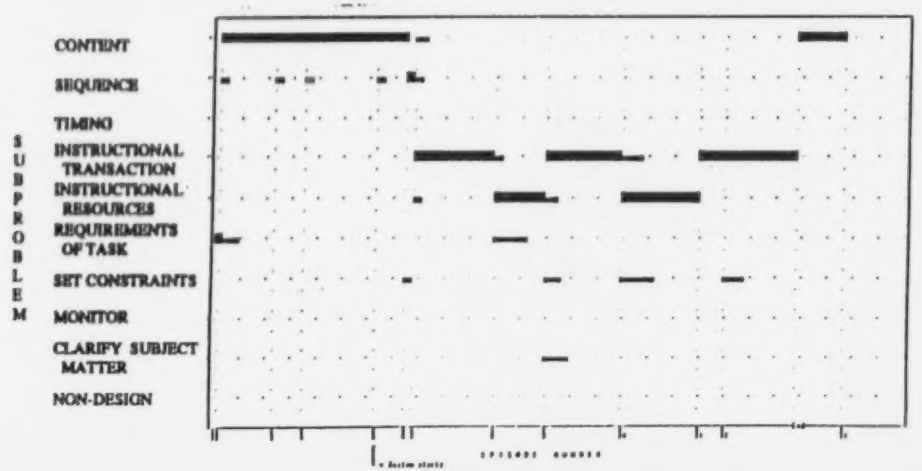


Figure IV-4

Subproblem type and duration as a function of episode number for transcript N3B-Principles.

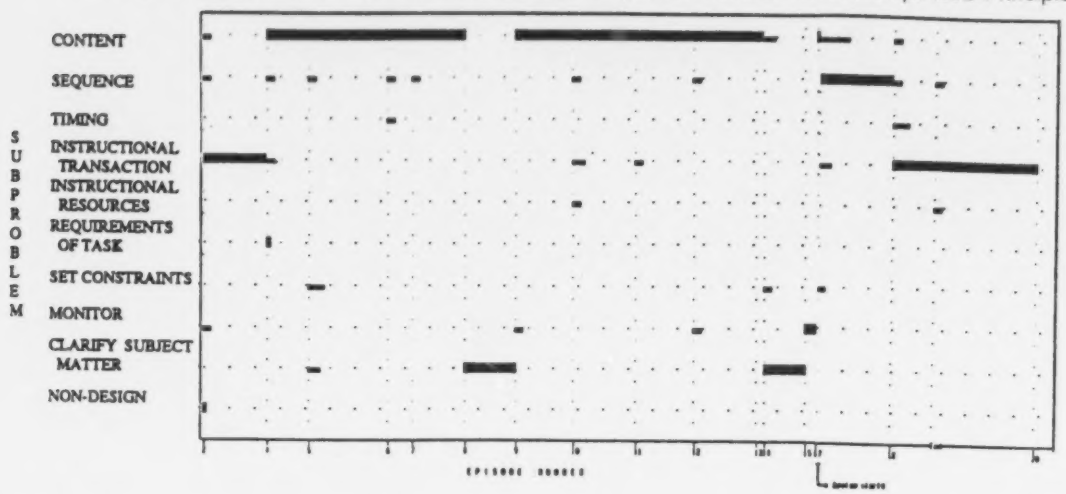
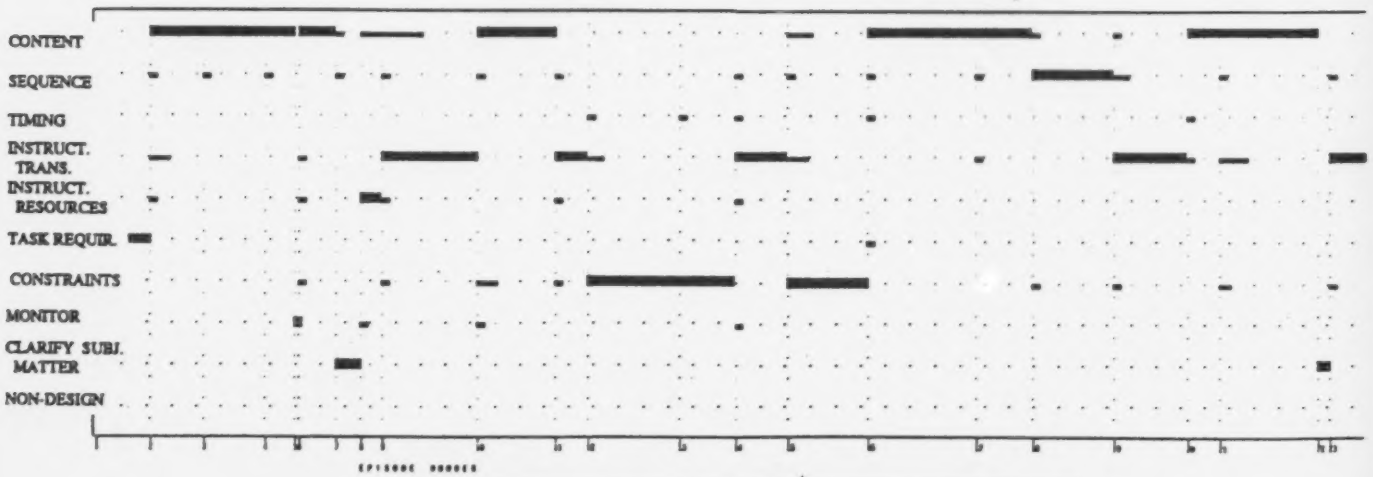


Figure IV-5

Subproblem type and duration as a function of episode number for transcript N3B-Operations.



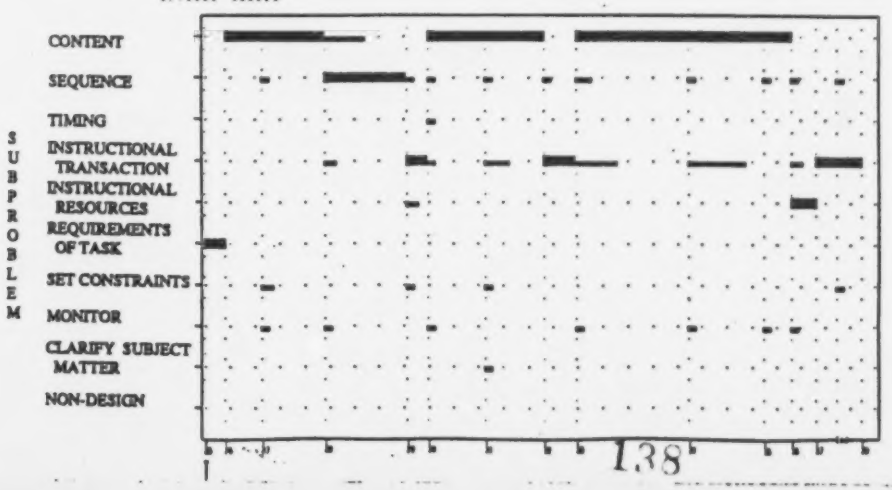


Figure IV-6

Subproblem type and duration as a function of episode number for transcript G2B-Principles.

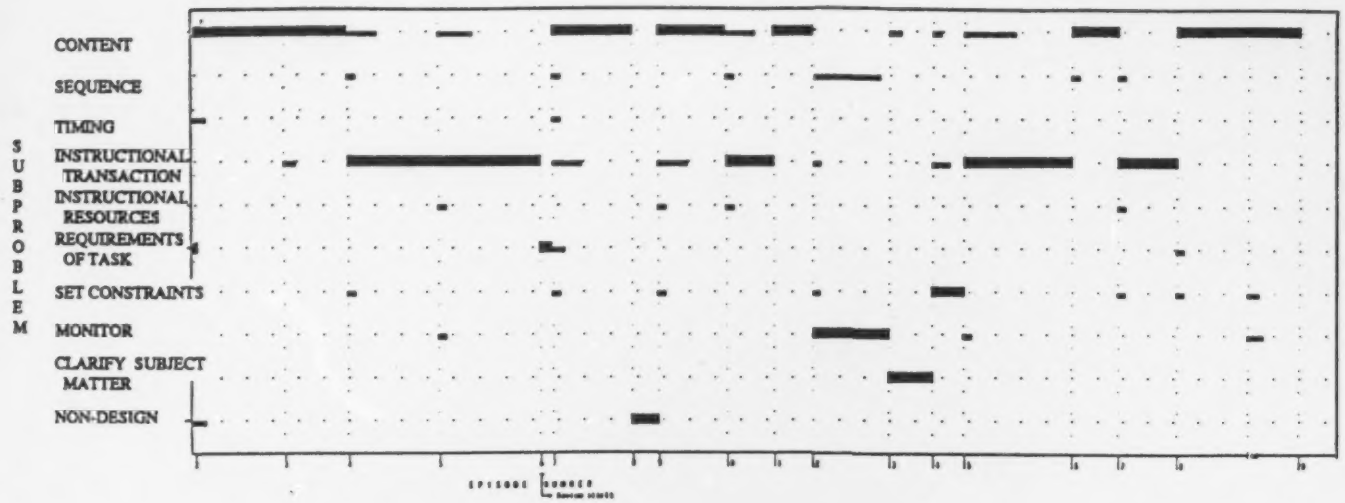


Figure IV-7

Subproblem type and duration as a function of episode number for transcript G4B-Principles.

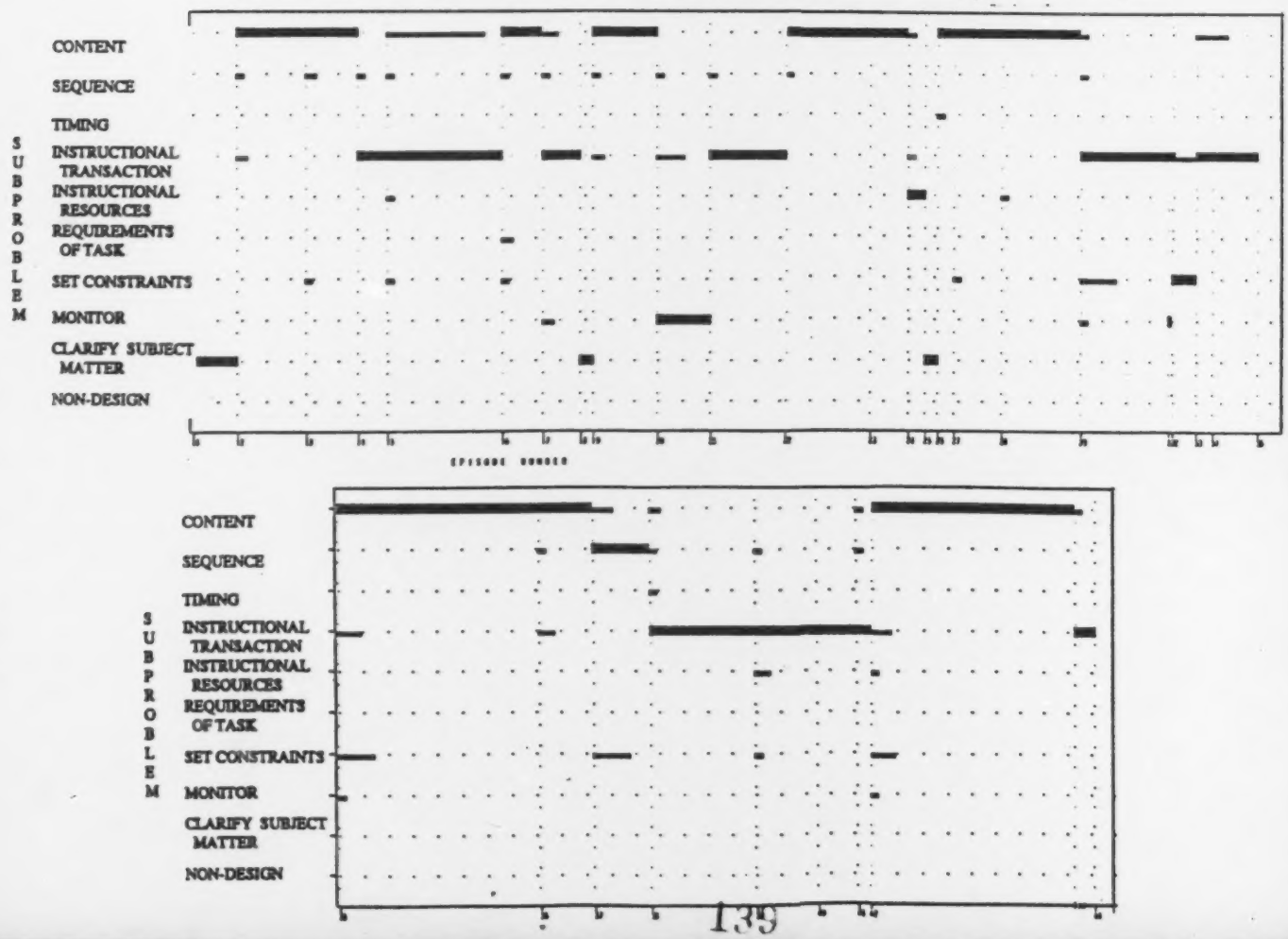
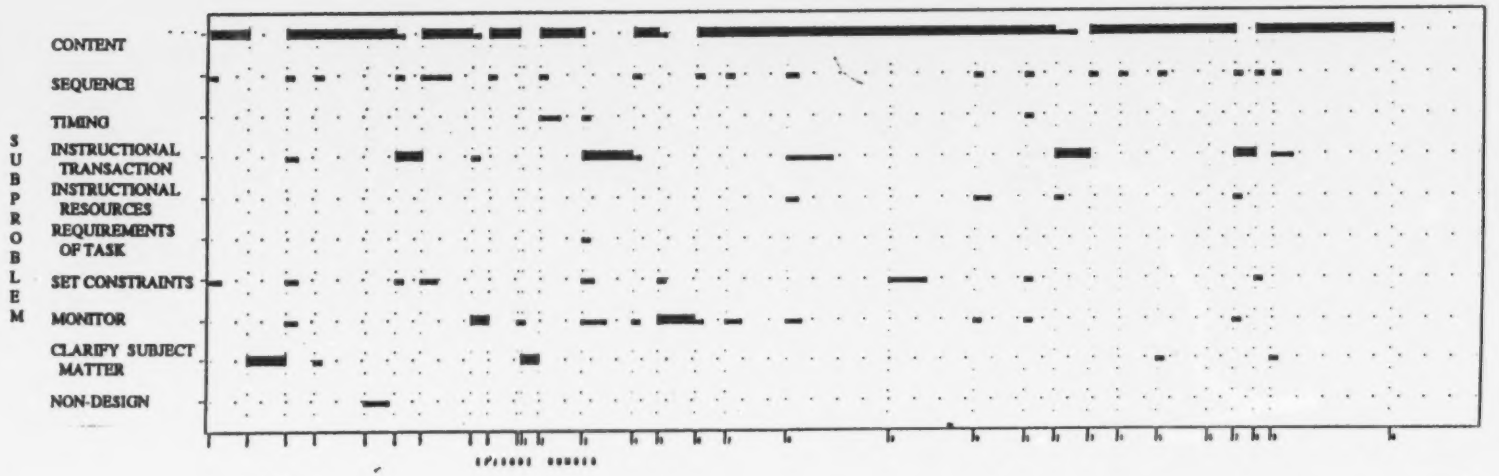
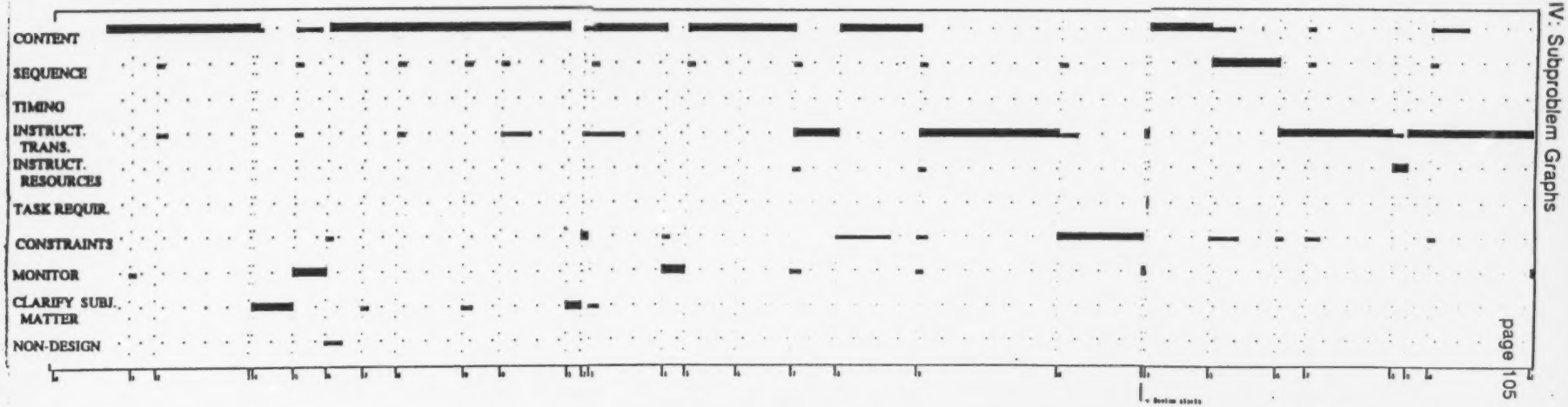


Figure IV-8
Subproblem type and duration as a function of episode number for transcript G4B-Operations.





Appendix V: **Knowledge Type Graphs**

Figure V-1

Knowledge type and duration as a function of episode number for transcript N1B-Principles.

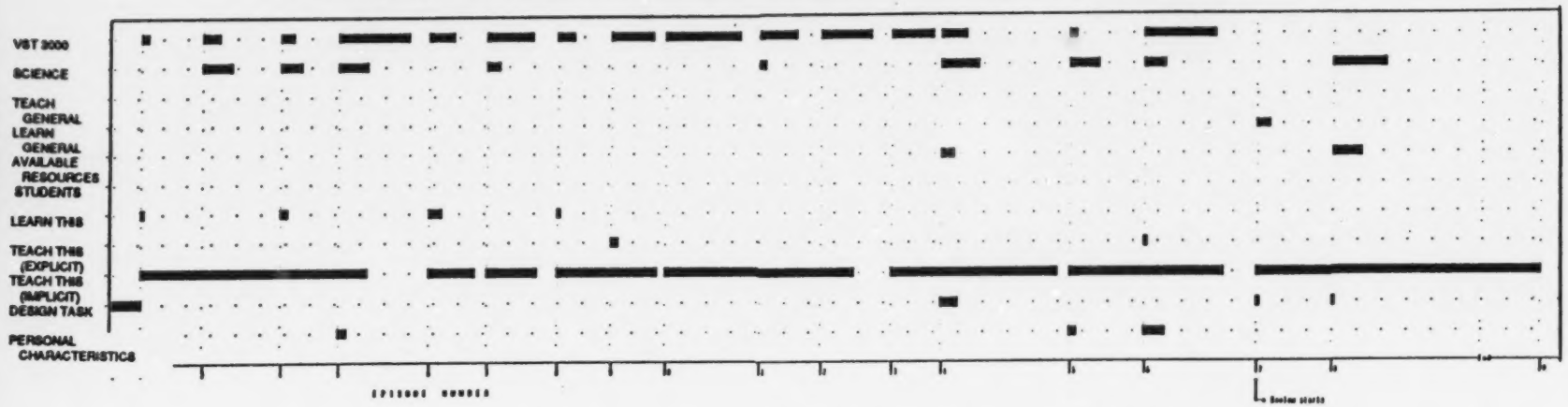


Figure V-2

Knowledge type and duration as a function of episode number for transcript N1B-Operations.

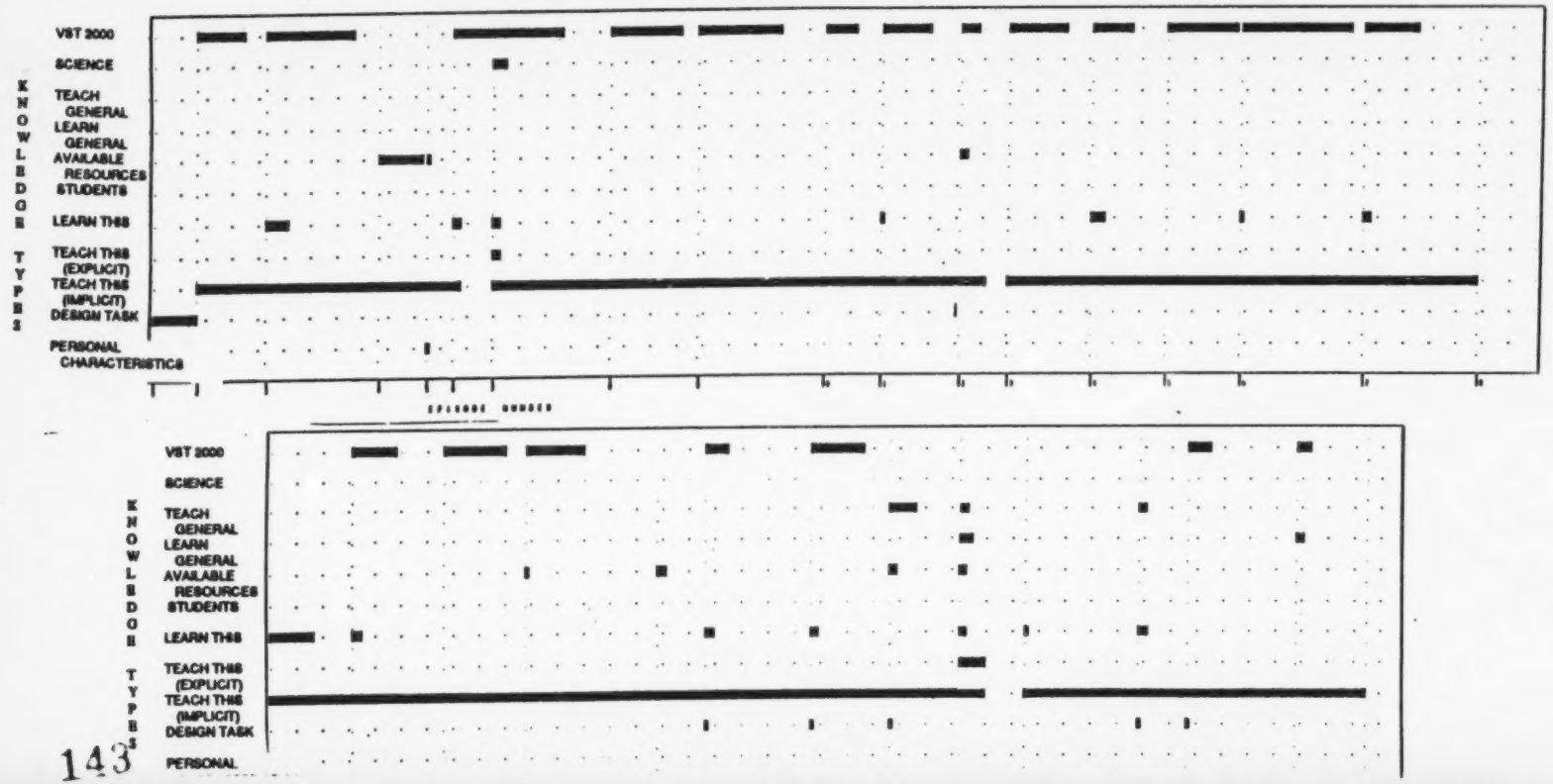


Figure V-3

Knowledge type and duration as a function of episode number for transcript N3B-Principles.

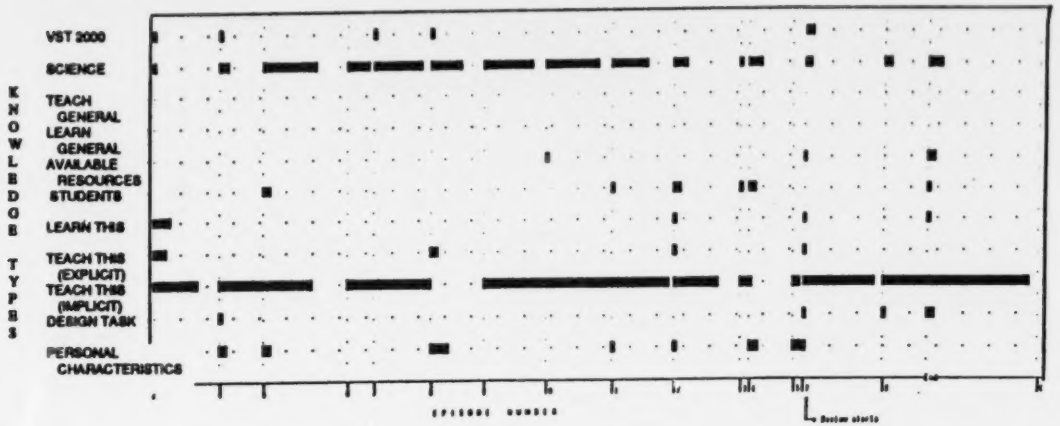


Figure V-4

Knowledge type and duration as a function of episode number for transcript N3B-Operations.

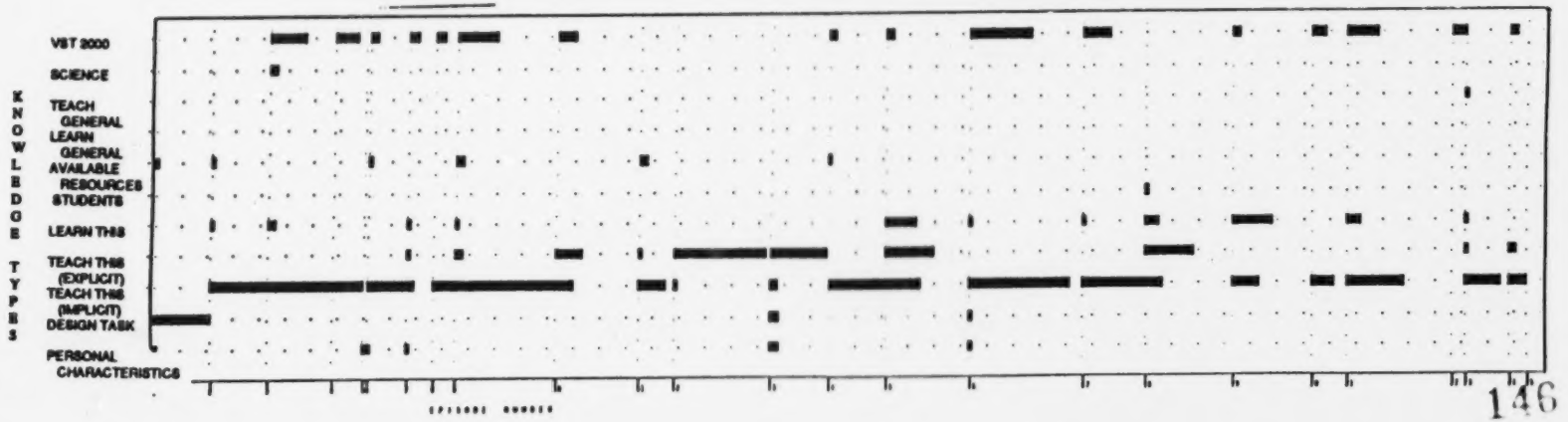


Figure V-5

Knowledge type and duration as a function of episode number for transcript N4A-Principles.

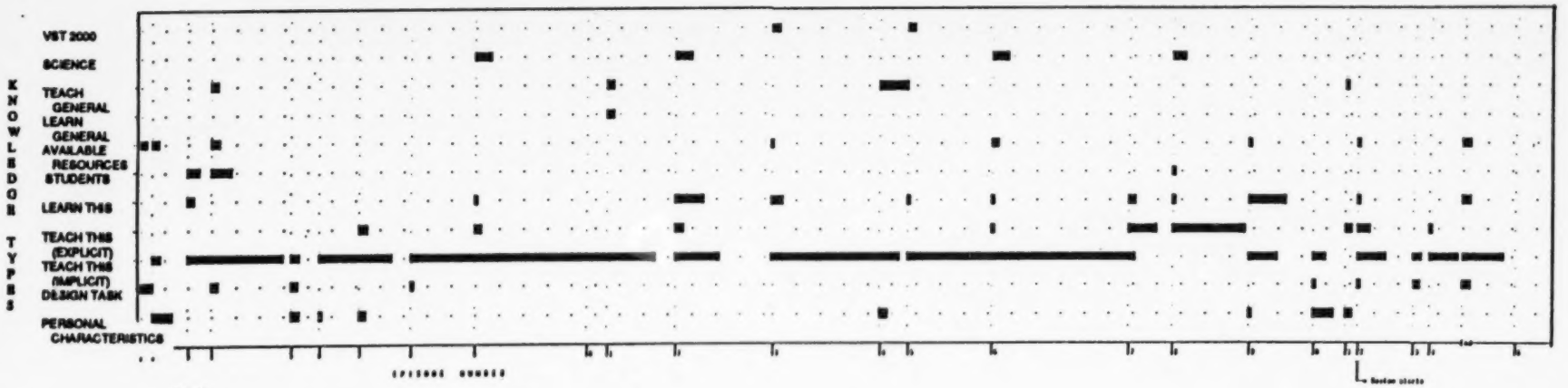


Figure V-6

Knowledge type and duration as a function of episode number for transcript N4A-Operations.

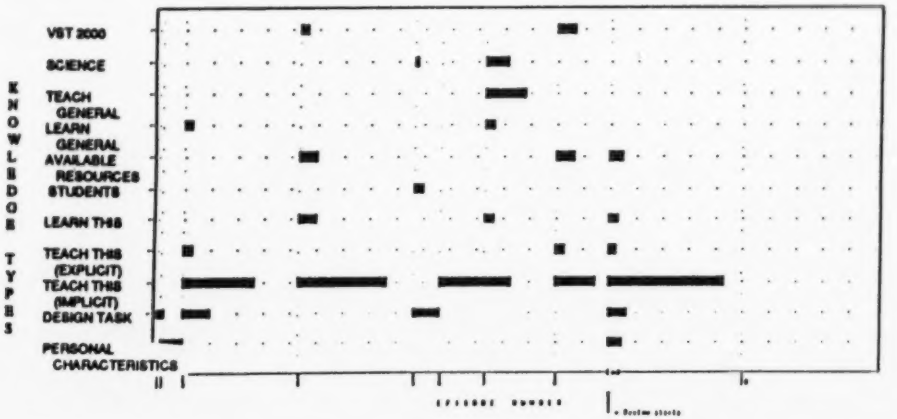
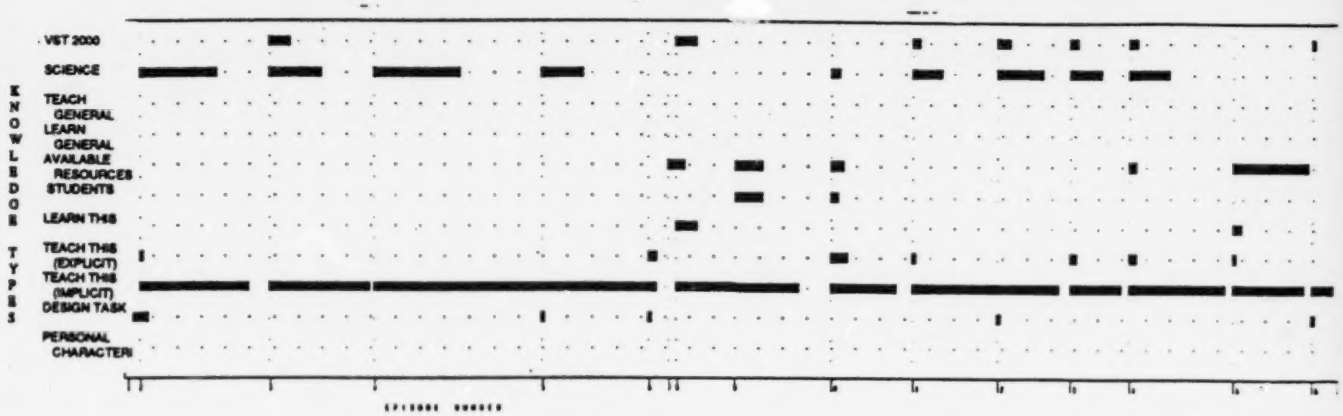


Figure V-7

Knowledge type and duration as a function of episode number for transcript G1A-Principles.



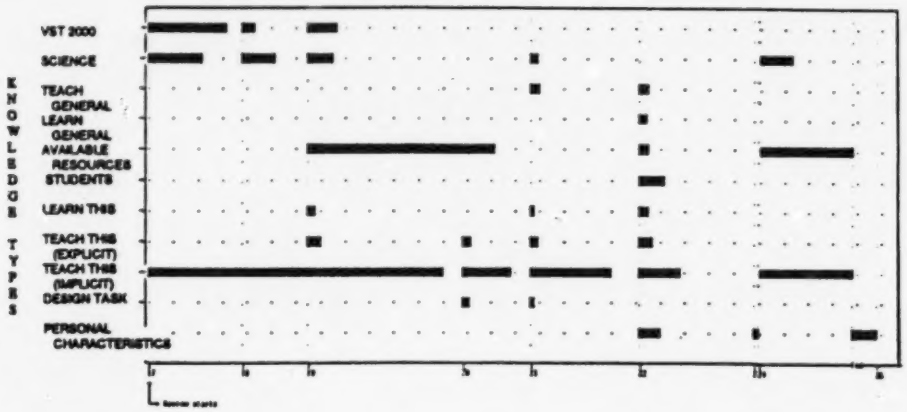


Figure V-8

Knowledge type and duration as a function of episode number for transcript G1A-Operations.

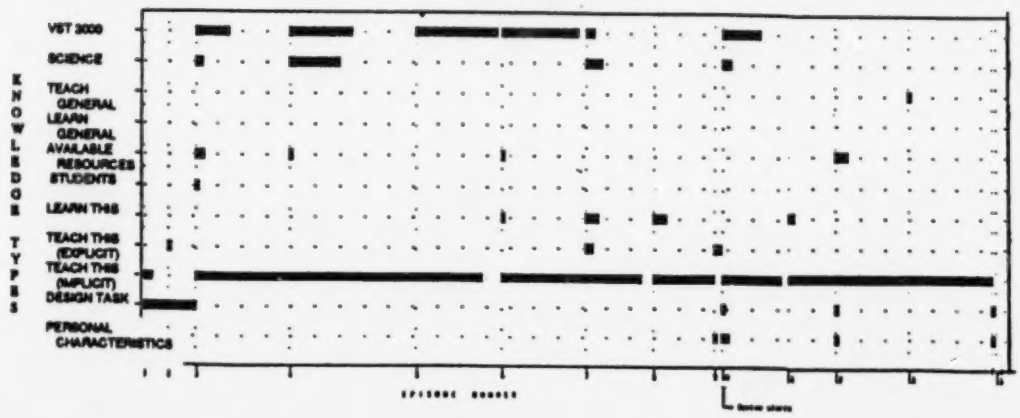


Figure V-9

Knowledge type and duration as a function of episode number for transcript G2B-Principles.

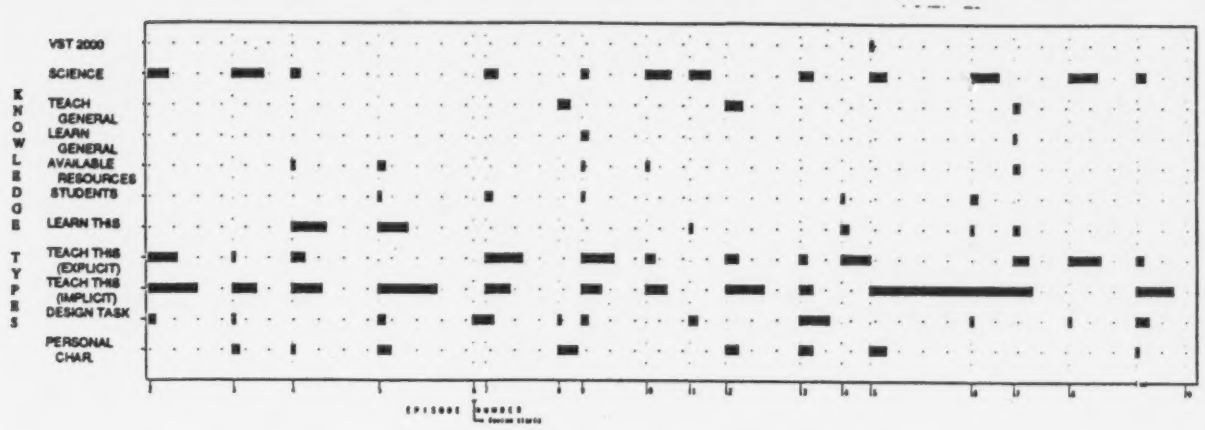


Figure V-10

Knowledge type and duration as a function of episode number for transcript G2B-Operations.

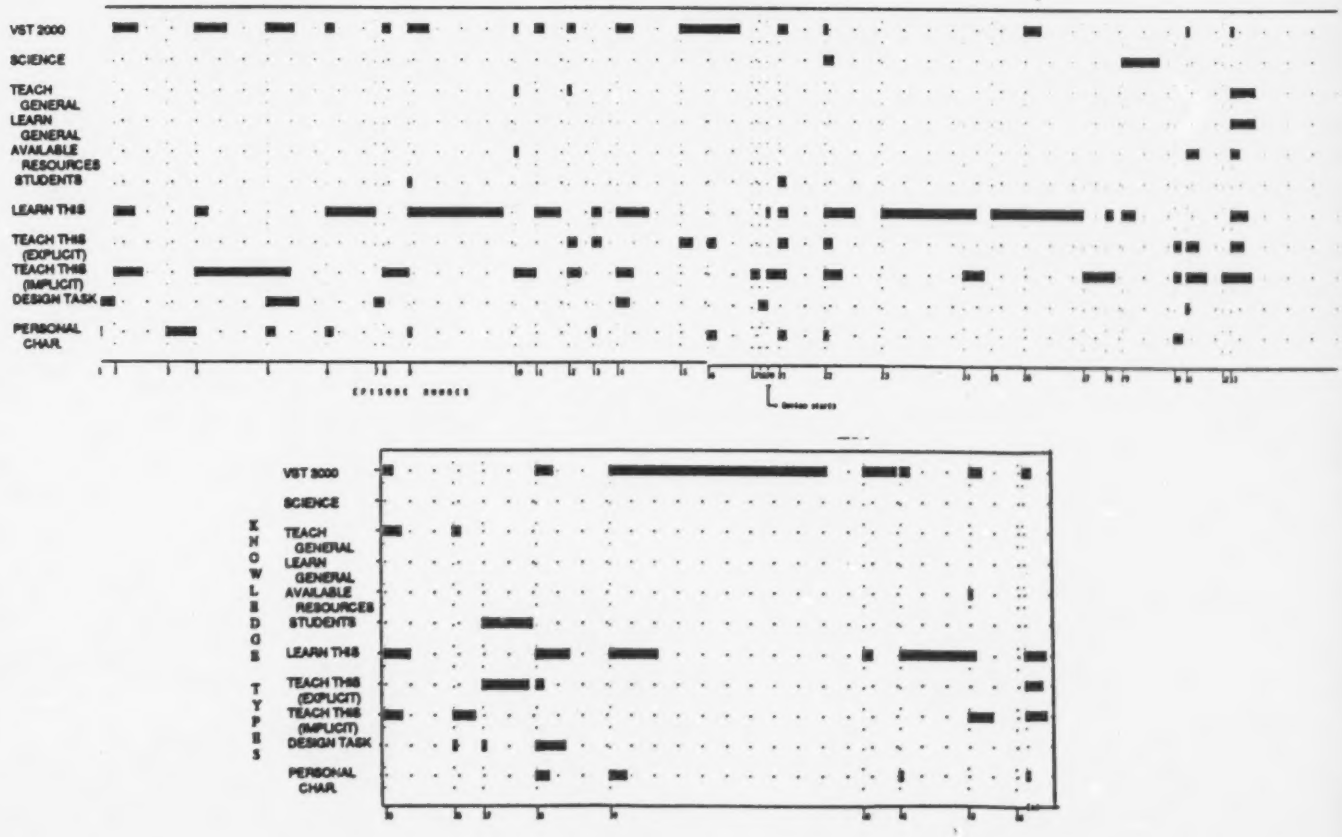


Figure V-11

Knowledge type and duration as a function of episode number for transcript G4B-Principles.

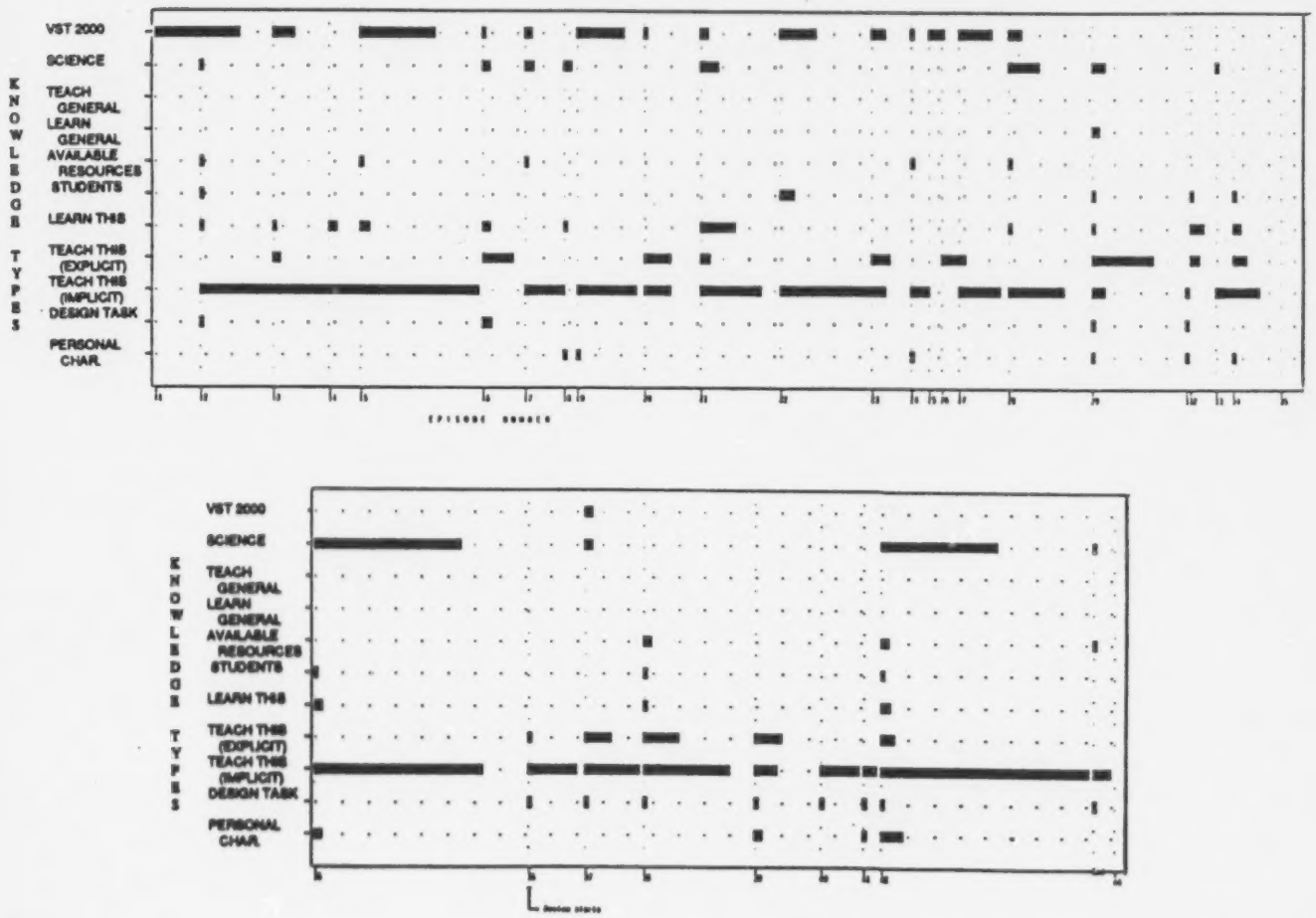
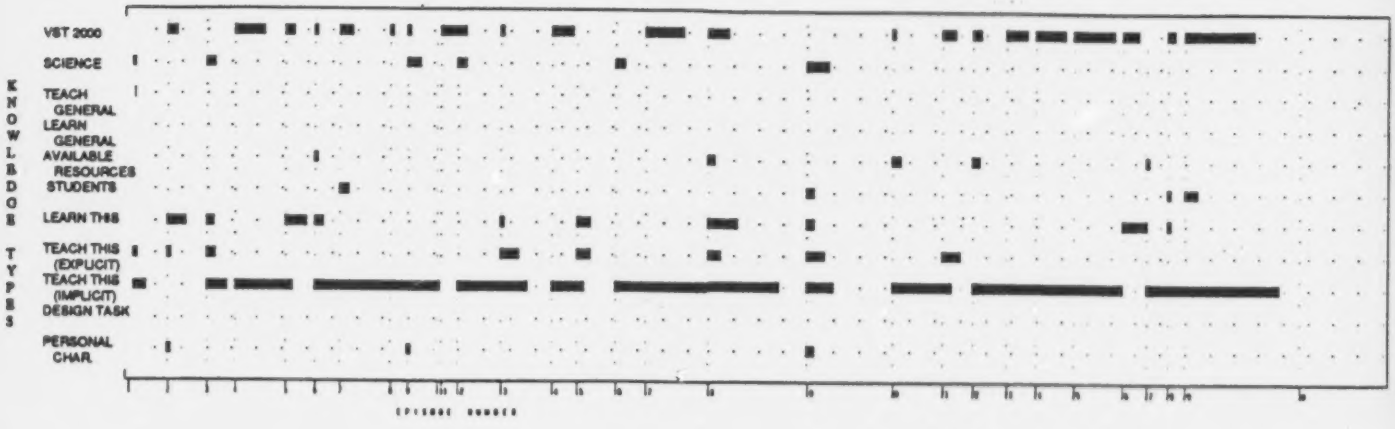
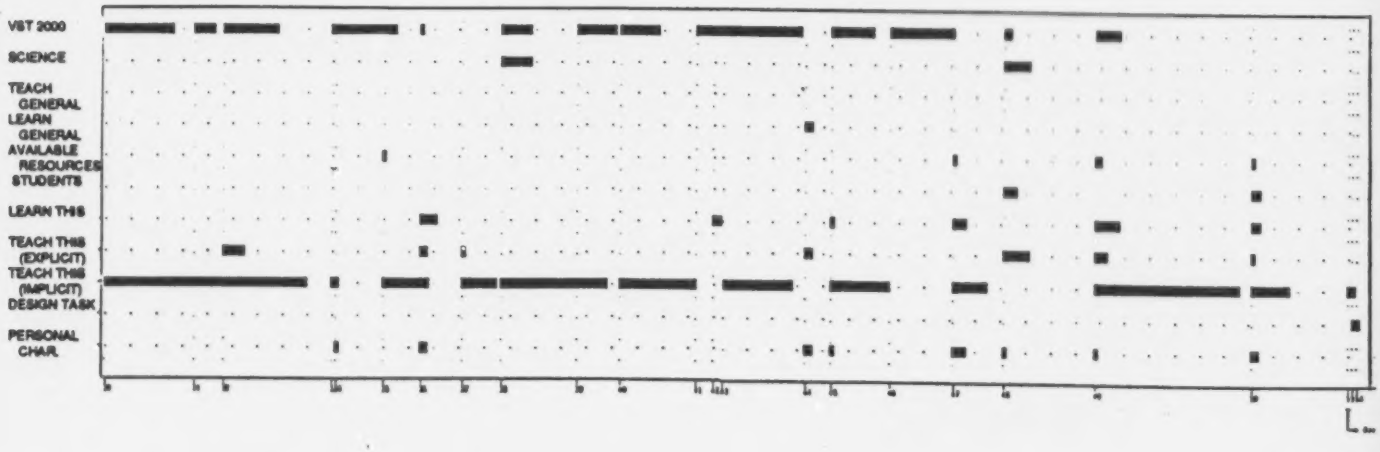
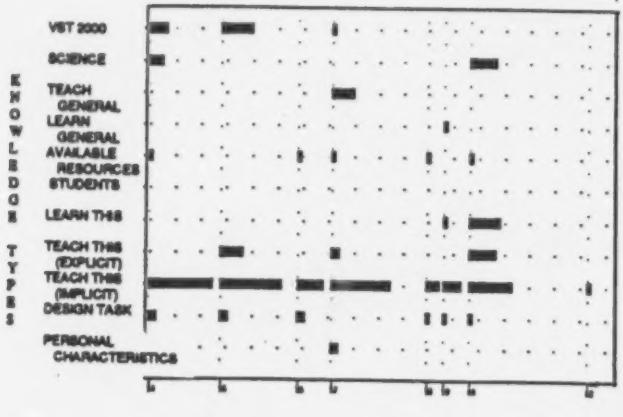


Figure V-12

Knowledge type and duration as a function of episode number for transcript G4B-Operations.







Appendix VI: Operator Graphs

Figure VI-1

Operator type and duration as a function of episode number for transcript N1B-Principles.

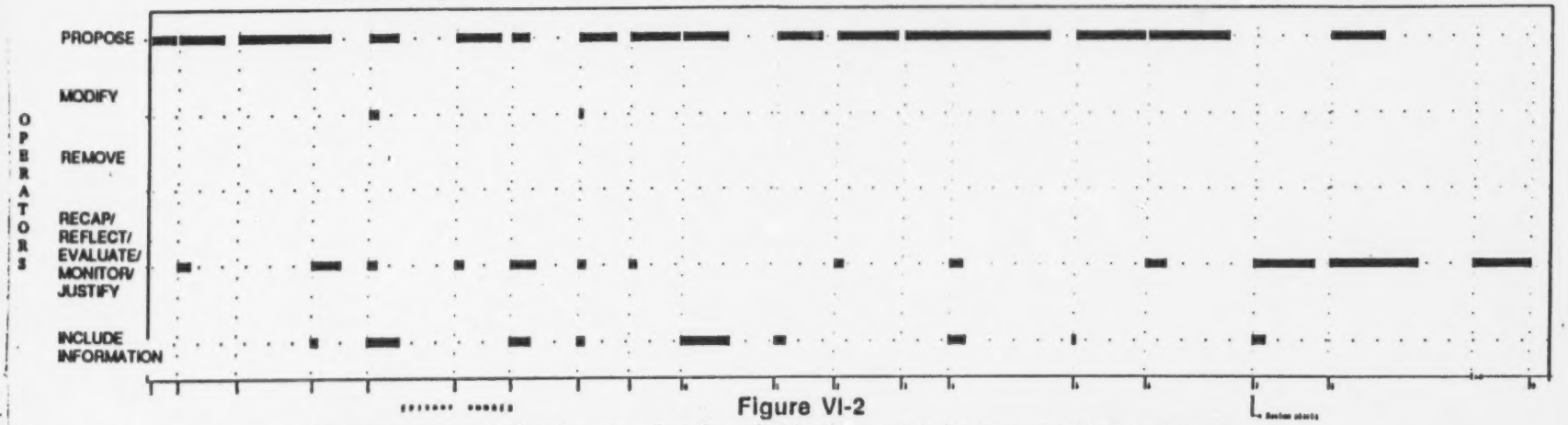


Figure VI-2

Operator type and duration as a function of episode number for transcript N1B-Operations.

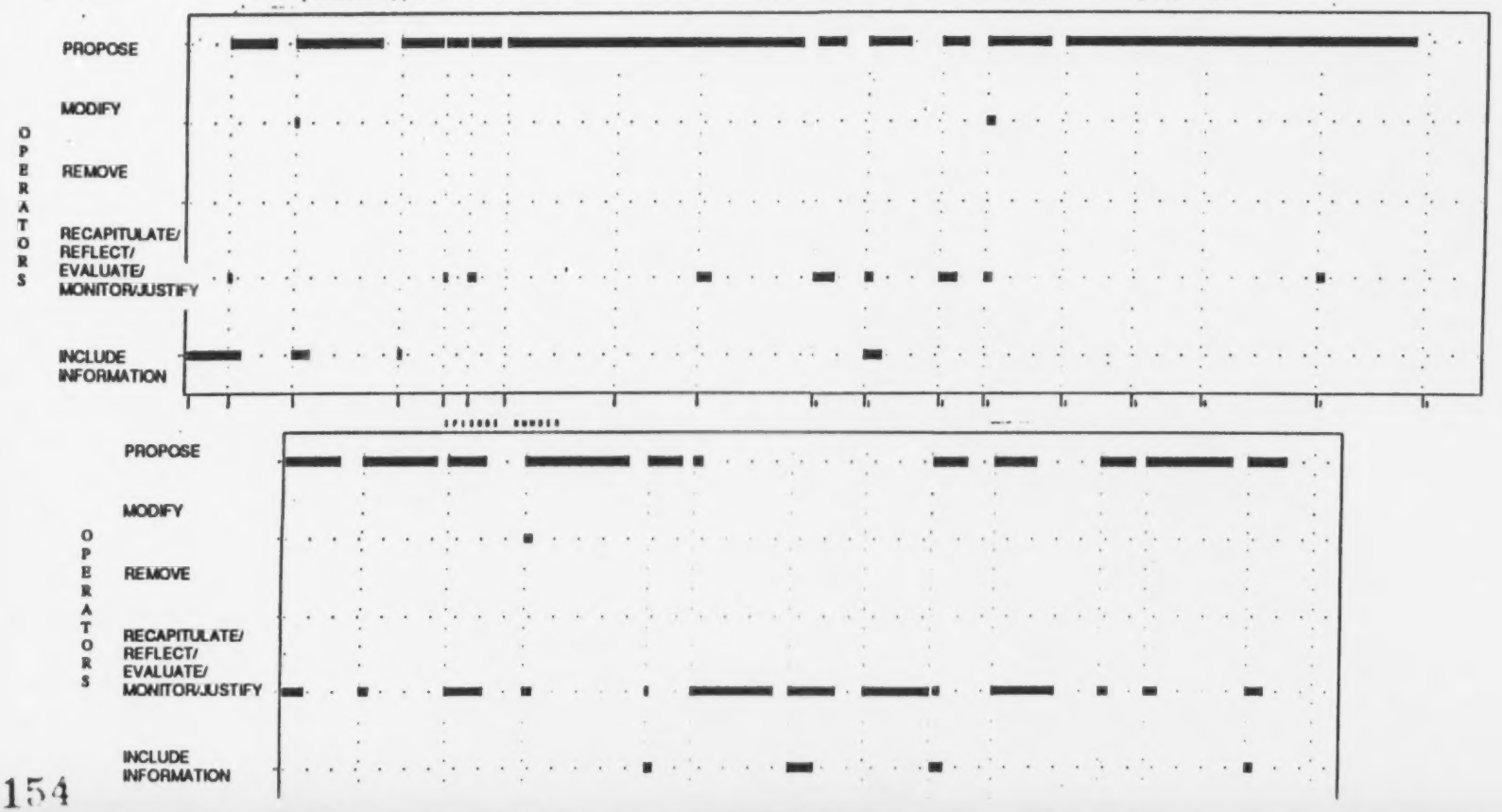


Figure VI-3

Operator type and duration as a function of episode number for transcript N2A-Principles.

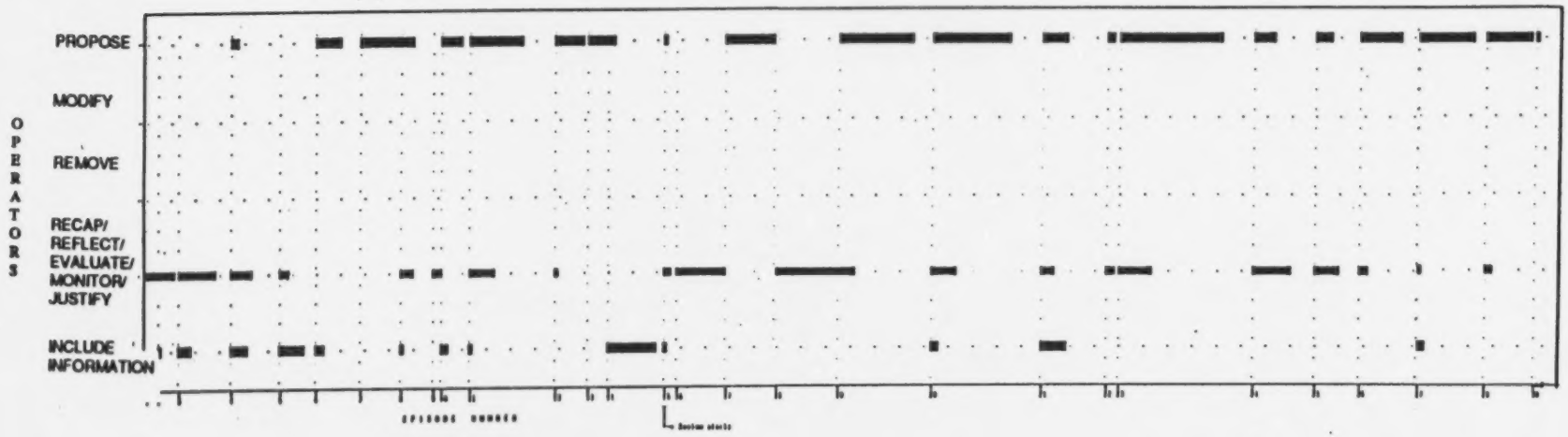


Figure VI-4

Operator type and duration as a function of episode number for transcript N2A-Operations.

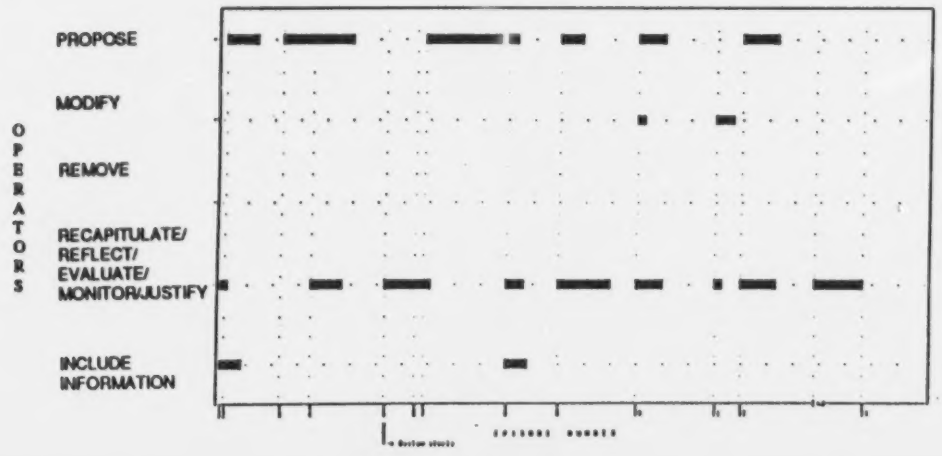


Figure VI-5

Operator type and duration as a function of episode number for transcript N3B-Principles.

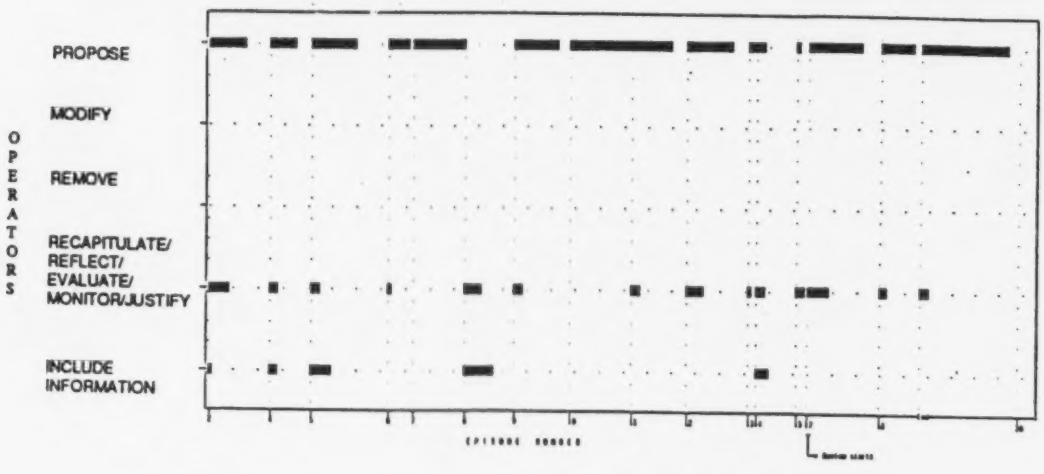


Figure VI-6

Operator type and duration as a function of episode number for transcript N3B-Operations.

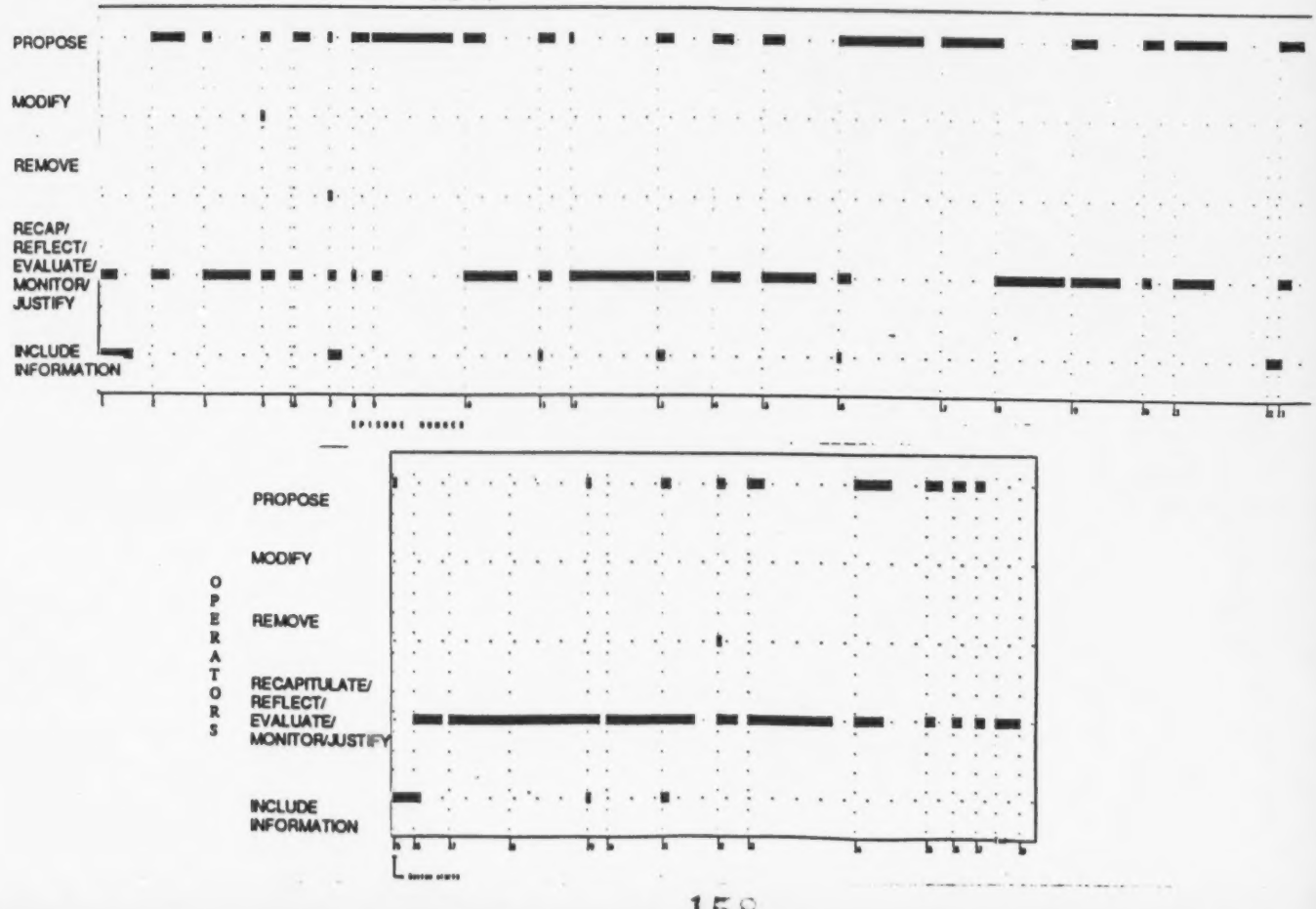


Figure VI-7
Operator type and duration as a function of episode number for transcript N4A-Principles.

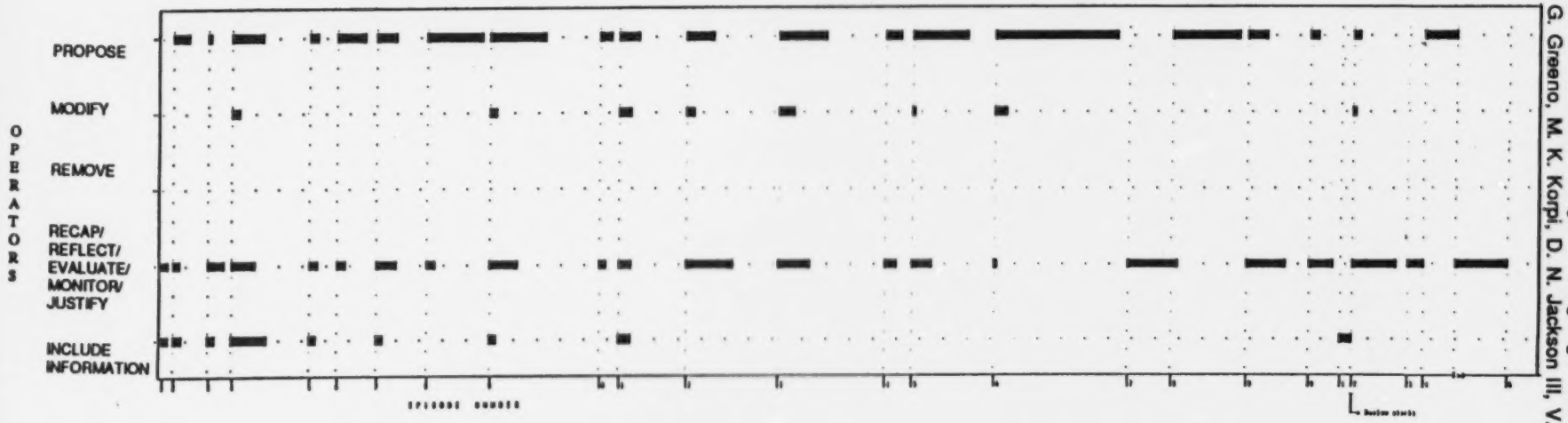


Figure VI-8
Operator type and duration as a function of episode number for transcript N4A-Operations.

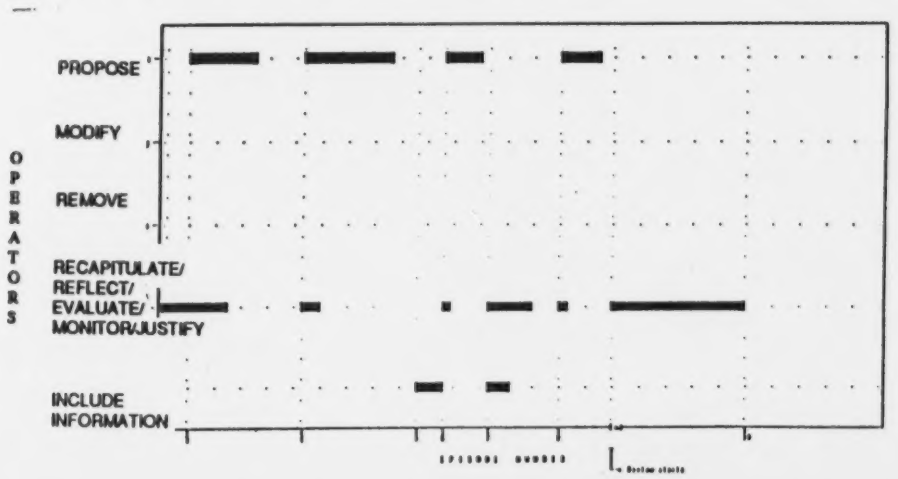


Figure VI-9

Operator type and duration as a function of episode number for transcript G1A-Principles.

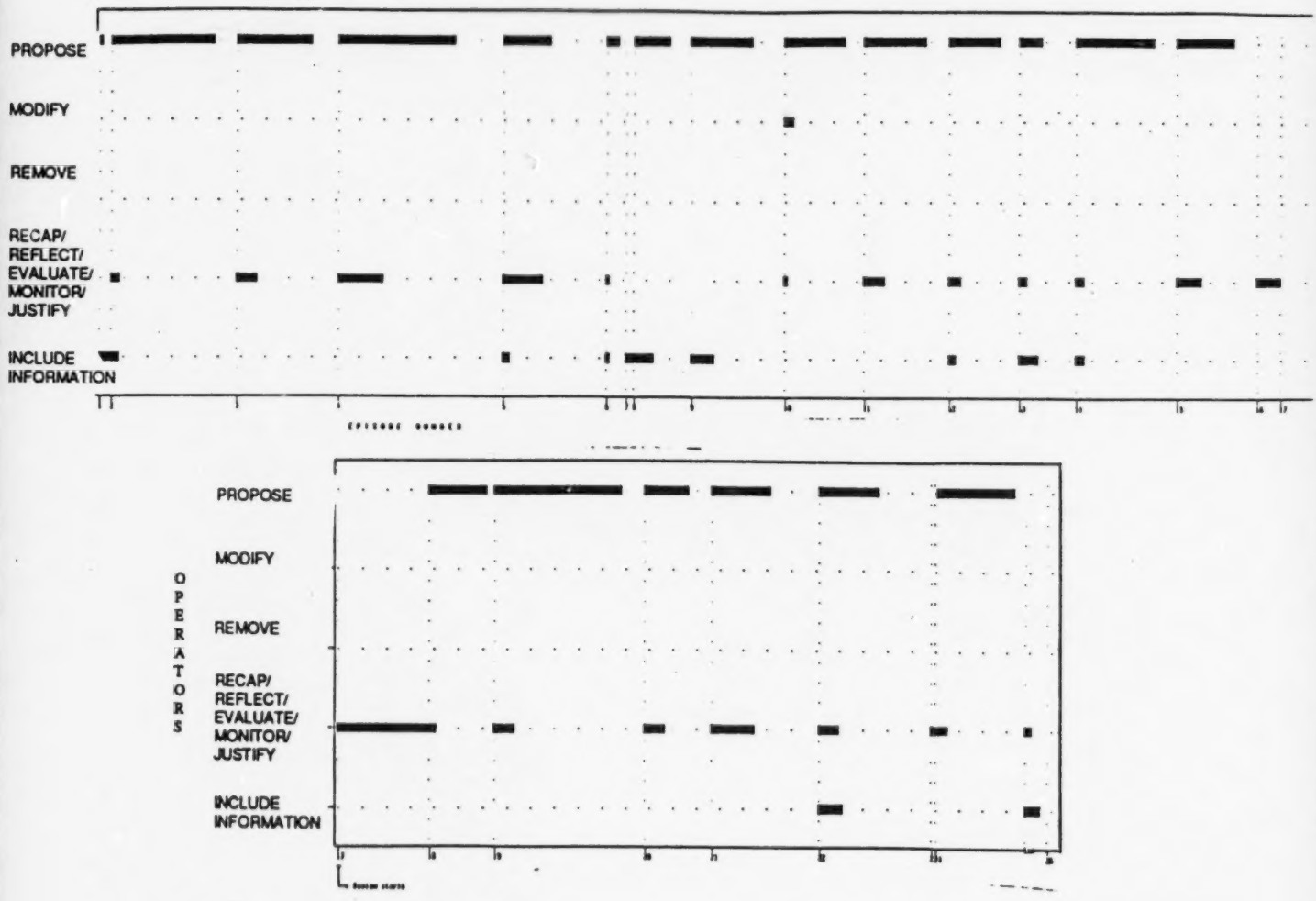


Figure VI-10

Operator type and duration as a function of episode number for transcript G1A-Operations.

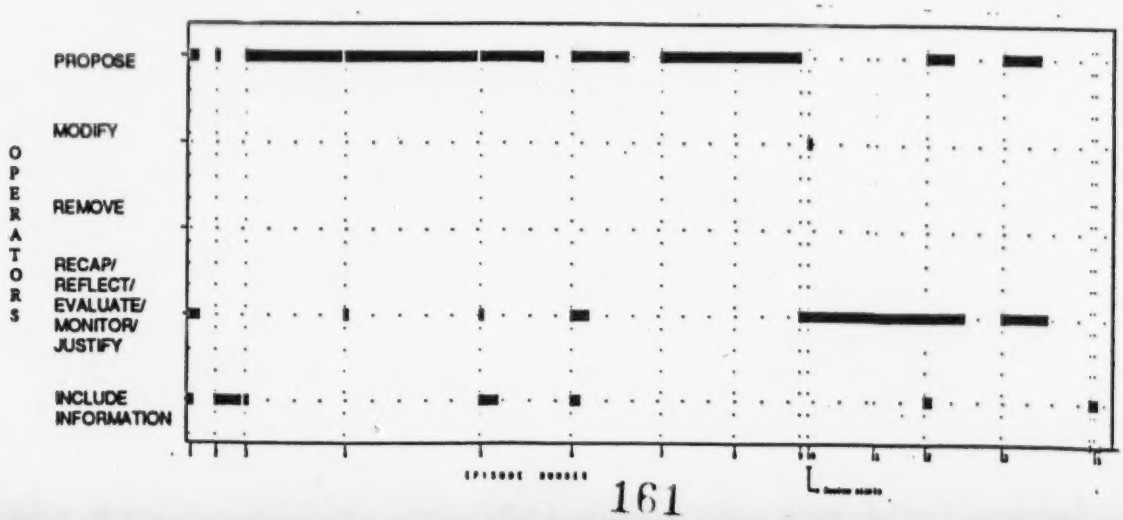


Figure VI-11

Operator type and duration as a function of episode number for transcript G2B-Principles.

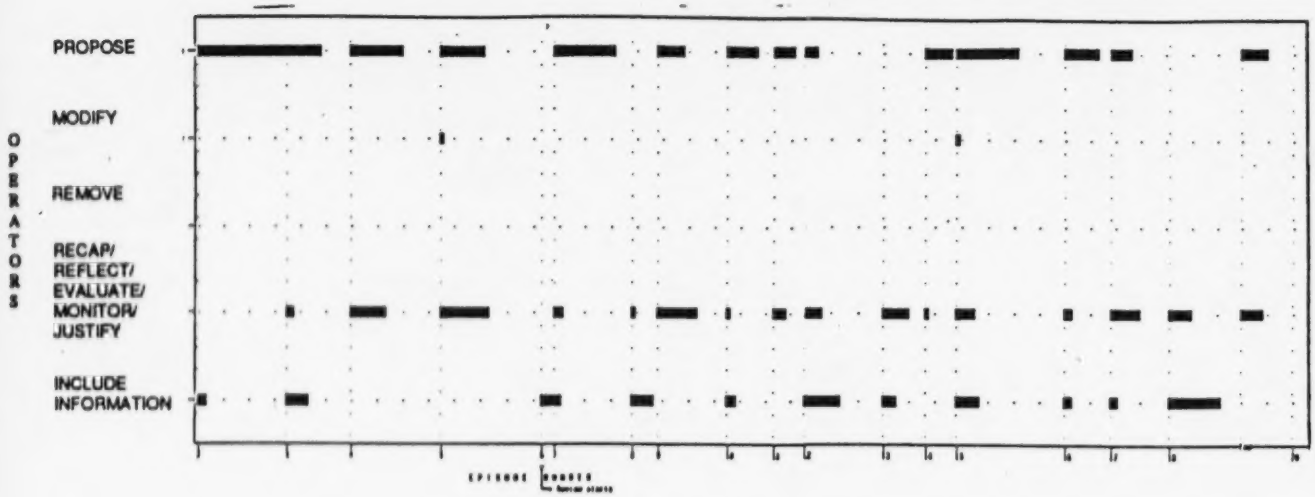


Figure VI-12

Operator type and duration as a function of episode number for transcript G2B-Operations.

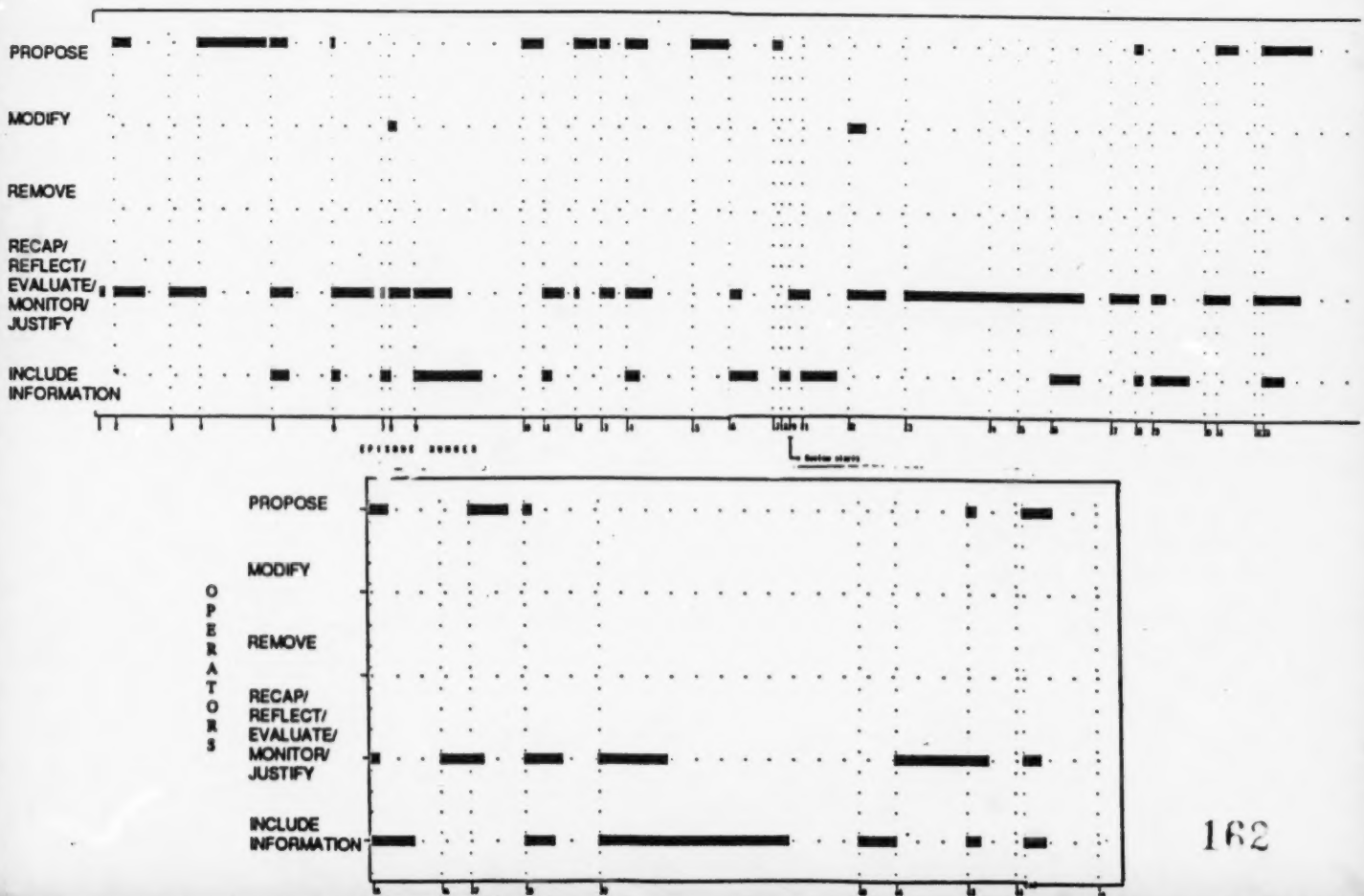


Figure VI-13

Operator type and duration as a function of episode number for transcript G3A-Principles.

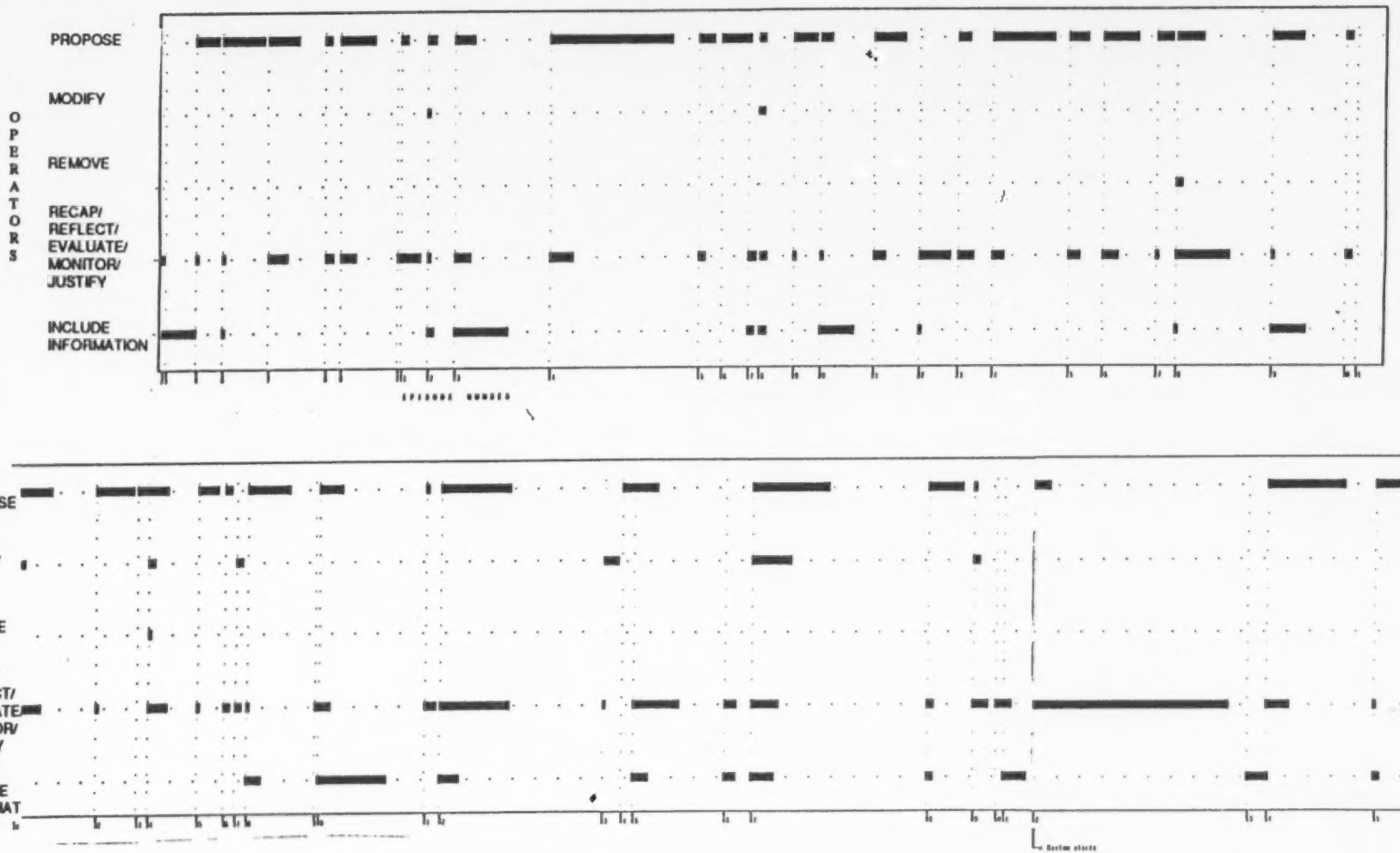


Figure VI-14

Operator type and duration as a function of episode number for transcript G3A-Operations.

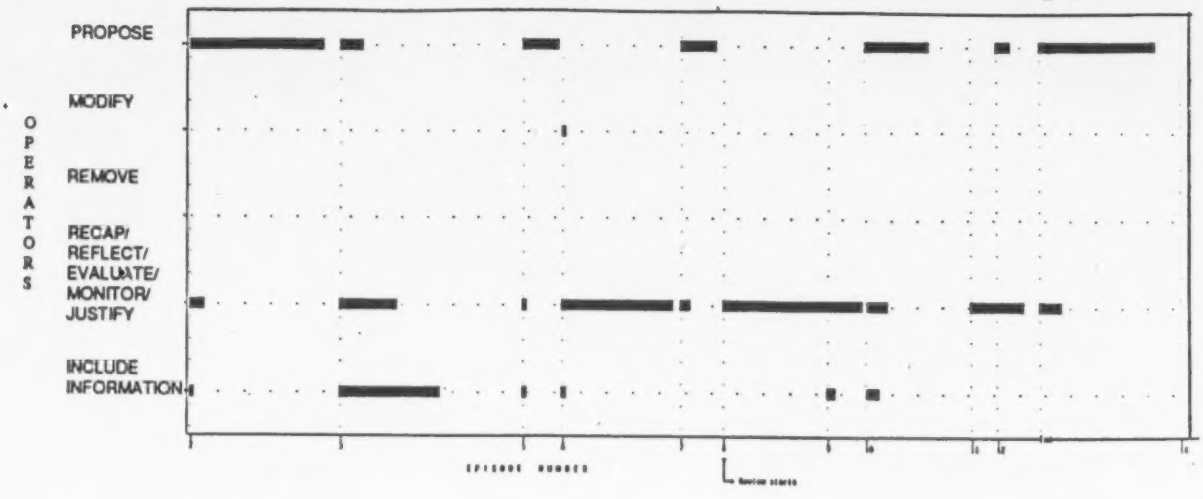


Figure VI-16

Operator type and duration as a function of episode number for transcript G4B-Operations.

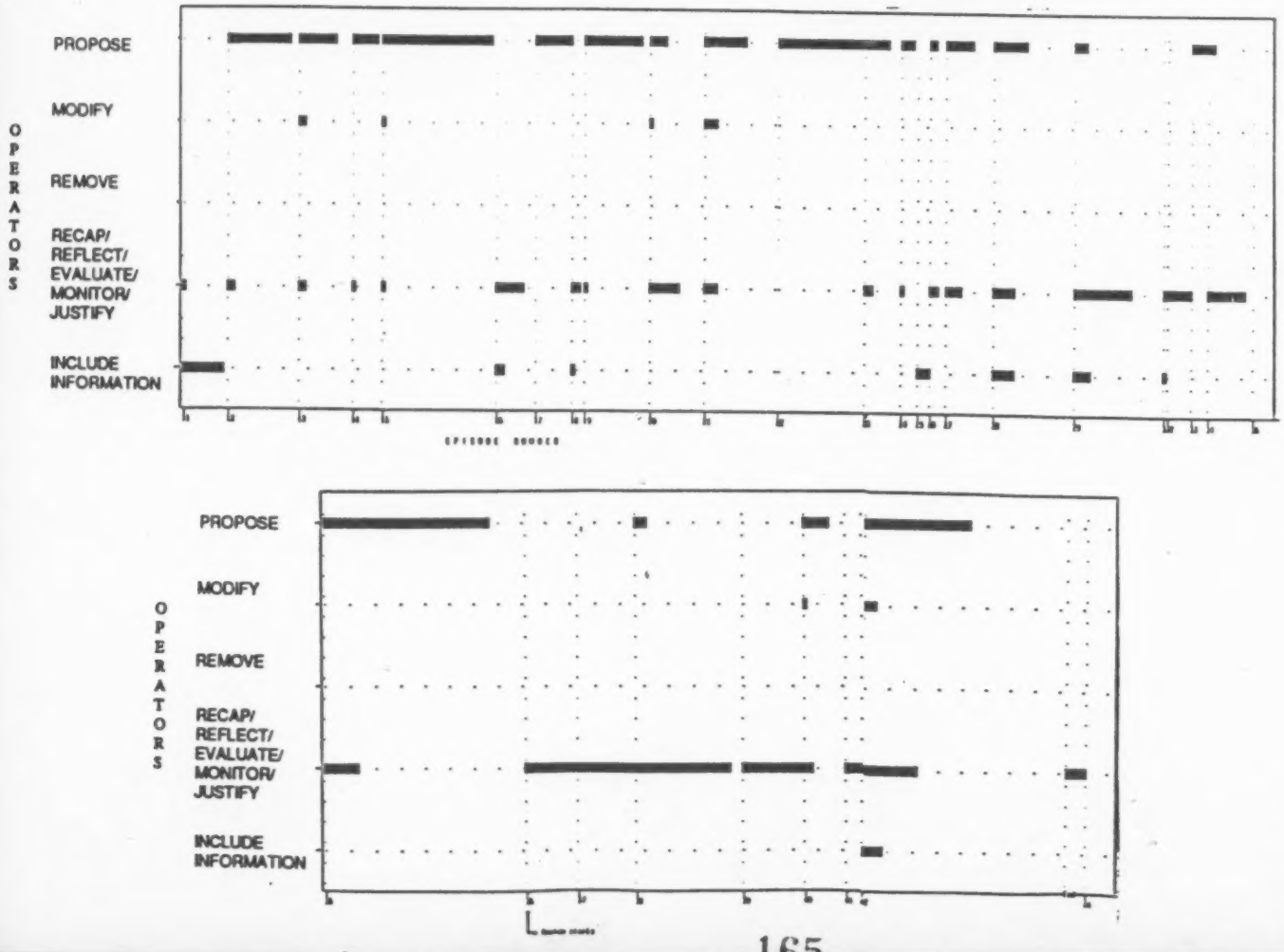
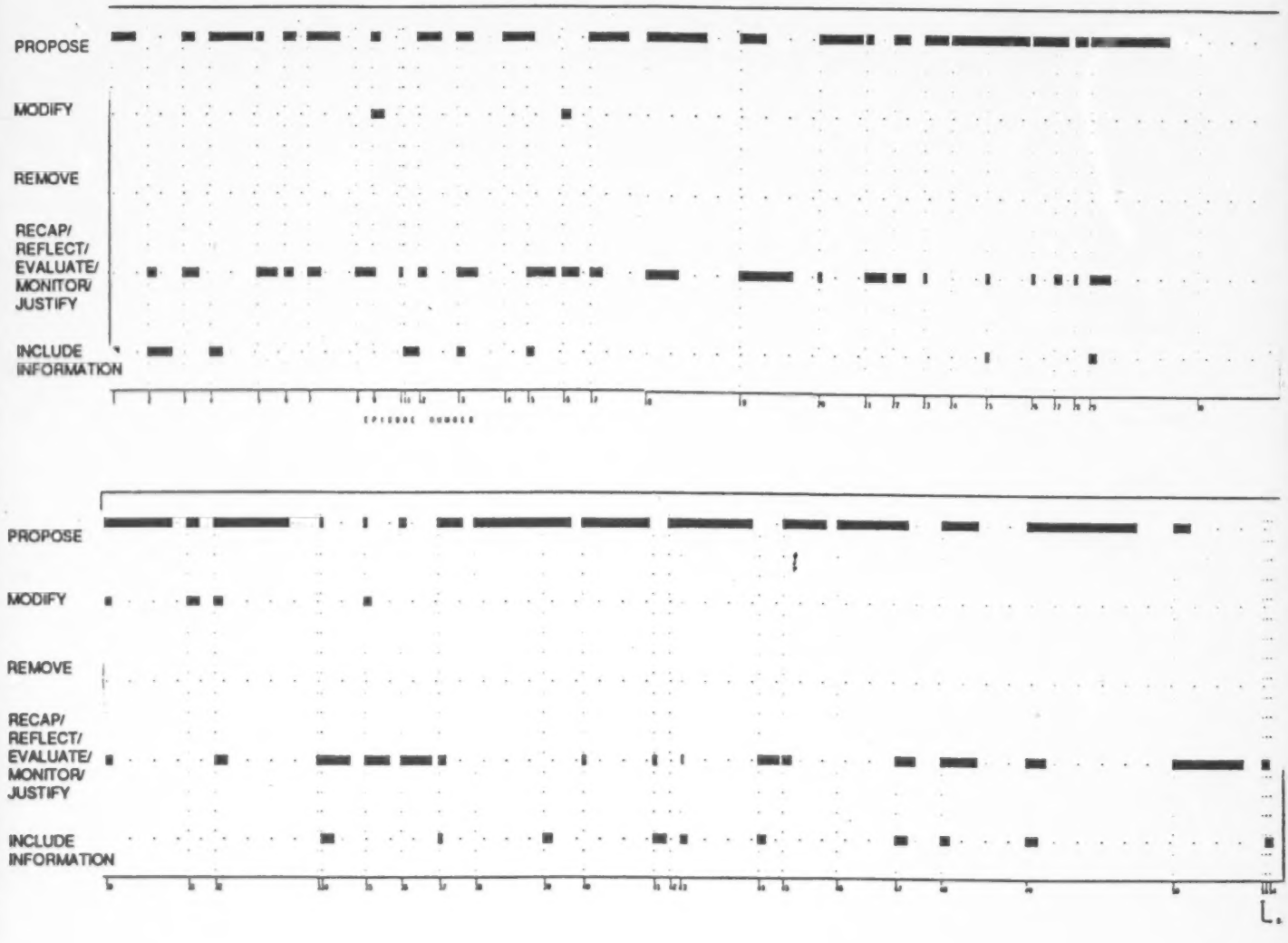
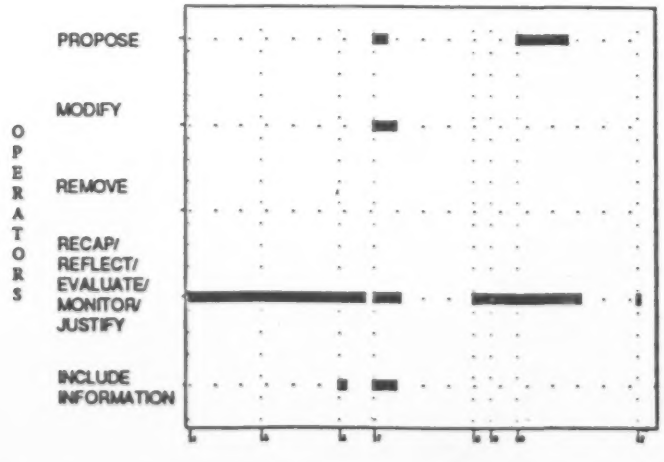


Figure VI-15

Operator type and duration as a function of episode number for transcript G4B-Principles.





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